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LABORATORY PROBLEMS IN PHYSICS

JONES AND TATNALL

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LABORATORY PROBLEMS IN PHYSICS

TO ACCOMPANY CREW AND JONES'S
"ELEMENTS OF PHYSICS"

BY

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AND

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PREFACE

THIS book is in part a liberal revision of Crew and Tatnall's "Laboratory Manual of Physics."

The writers have attempted, —

(1) As in the original text, to place the emphasis upon the problem to be solved (fact or principle to be learned), rather than upon the method to be employed.

(2) To stimulate the pupil's interest and assist his reasoning by means of leading questions. To some the answers are self-evident; to the remainder they may easily be found by a little thought or finally by reference to the textbook. Questions of this sort give a definite aim and prevent diffuse reasoning.

(3) To provide directions and to describe apparatus characterized by the utmost simplicity. The directions will apply to any standard form of apparatus. Special sets of apparatus for these experiments are unnecessary.

(4) To emphasize the practical importance of each problem by questions at the close of the exercise upon its "Application."

(5) To avoid retardation of the lesson assignments because of the laboratory work. Laboratory and lessons from the textbook must accompany each other upon the same topic at the same time. At no time must the former be allowed to retard progress — better omit a few desirable experiments altogether or postpone them until the review.

(6) To call attention to the value of a thorough review by marking some experiments "Review Experiments." All the experiments thus marked can be more profitably performed after a preliminary view of the subject; namely, on the review.

While these exercises may be used in connection with any textbook, the order adopted is that of Crew and Jones's "Elements of Physics."

A large number of the cuts have been drawn by Mr. H. B. Spelman of University School. Some have been borrowed from apparatus catalogues.

Tables of properties of various substances are not included in this book. Each laboratory should be provided with a copy of "Smithsonian Physical Tables" (published by the Smithsonian Institution, Washington, D.C.), from which all necessary information of this kind may be obtained.

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LABORATORY PROBLEMS IN PHYSICS

A VALUE FOR Π

Problem. — To measure π, the ratio between the circumference of a circle and its diameter.

Apparatus. — Several circular disks of different sizes — sections of curtain rod are very satisfactory; sharp, hard lead pencil; ruler.

Experiment. — Draw a line on a sheet of paper and make a mark *B* (Fig. 1) near one end. Make a mark *A* on one of the disks. Set the mark *A* on *B* and roll the disk along the sheet of paper until the mark *A* is again in contact with the line. Mark this point of contact *C*. What is the relation between the length of the line *BC* and the circumference of the disk?

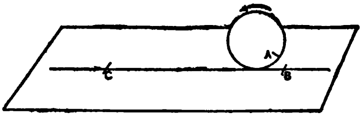


FIG. 1. — Finding π

Repeat this operation three times and arrange the results in a tabular form, thus:

Disk	1	2	3	Average
Circumference				
Diameter				
π				

$$\frac{\text{circumference}}{\text{diameter}} = \pi.$$

Note. — The tabular forms in this book are given as models that the student may be taught to arrange his work systematically. They are purposely made too small for the recording of observations.

Make the same observations for the other two disks. Compare the three values of π thus obtained. Is π a constant; *i.e.* is the value of π independent of the size of the disk?

To how many places of decimals may π be accurately determined by this method? How many decimal places will you, therefore, retain in your answer?

CURVE PLOTTING. *A*

Problem. — To represent the position of a point on a plane surface.

Apparatus. — Cross-section paper ruled in large and small squares; sharp, hard lead pencil; ruler.

Experiment. — Along heavy lines through the middle of a sheet of cross-section paper draw two lines, one horizontal, the other at right angles to it.

Their intersection is called the **origin.** The horizontal line is called the **axis of X.** Its extremities are lettered XX'. The line at right angles is called the **axis of Y.** Its extremities are lettered YY'. Distances measured along or parallel to the axis of X are called **abscissas.** They are **positive** when measured **to the right; negative** when measured to the **left** of the Y axis. Distances measured along or parallel to the axis of Y are called **ordinates.** When measured **above** the X axis, they are **positive**; when measured **below** the X axis, they are **negative.**

Locate the point whose abscissa is $+2$ and whose ordinate is -1.

Show the work to the instructor before proceeding.

Locate the following points, using one large square as unity:

Abscissa	$+3$	$+4$	-2	-5.
Ordinate	$+5$	-2	$+3\frac{1}{2}$	-4.

In which quadrant does each one of these points lie?

Write a concise statement describing how to locate any point whose abscissa and ordinate are known and how to find the abscissa and ordinate of any point whose position is known.

CURVE PLOTTING. *B*

Problem. — To construct the graph of the equation, $y = 2x$.

Apparatus. — Cross-section paper; hard lead pencil; ruler.

Experiment. — Take another sheet of cross-section paper. In the upper left-hand corner arrange values of x and corresponding values of y — given by the equation $y = 2x$ — in columns, thus:

x	y
0	0
1	2
2	?
3	. . .
4	. . .
−1	. . .
−3	. . .
−5	. . .

Plot these eight points and connect them with a smooth curve. What is its form?

Any such equation as $y = 2x$ says that one number y is proportional to another x. Write a concise statement describing the curve which expresses this fact.

CURVE PLOTTING. *C*

Problem. — To construct some curves showing the relations of physical quantities.

Apparatus. — Cross-section paper; hard, sharp pencil; ruler.

Experiment. — (1) Draw the curve showing the relation between pressure and depth of water in a tank from the following data:

Depth of Water in Feet	Pressure in Pounds per Square Foot
0	0
1	62.5
2	125.
4	250.
6	375.
8	500.
10	625.

As axis of Y, take the left-hand margin of a fresh sheet of cross-section paper. As axis of X, take the bottom of the sheet. Plot depths as ordinates, using one large square = one foot, and pressures as abscissas, using one large square = 62.5 lb.

From the curve how can you describe the relation between pressure and depth?

Draw a curve showing the relation between the volume of a given mass of gas and the pressure upon it at constant temperature from the following data:

VOLUME IN CC.	PRESSURE IN CM. OF MERCURY
5.	1520
7.6	1000
10.	760
15.	507
20.	380
25.	304
40.	190
50.	152
76.	100
100.	76
150.	51

As before take the bottom and left hand margin of the cross-section paper as the axes. Plot volumes as abscissas using 1 small square = 1 cc.

Plot pressures as ordinates using 1 large square = 100 cm. of mercury.

Plot the points given in the table and connect with a smooth curve. When two quantities are inversely proportional, the relation between them is represented by a line of this shape. What is the relation between the volume of a given mass of gas and the pressure upon it?

Draw a curve showing the relation between the temperature of water and its volume.

For values use the table on page 217, Crew and Jones, "Elements of Physics." The first column in the table gives the abscissas, and the last column the ordinates of the curve. Use the bottom of the paper as the axis of *X*, the left-hand margin as the axis of *Y*. Along the *X* axis take 1°=3 small squares. Along the *Y* axis take .0001 = 2 small squares. Let the *X* axis represent 1.000000. All points of the curve will then lie above the *X* axis and to the right of the *Y* axis.

THE VERNIER CALIPER

Problem. — (1) To make a vernier caliper.

Apparatus. — A piece of bristol board about 8 × 3 in.; a metric rule (preferably a 20-cm. steel scale); a sharp knife or shears.

Experiment. — Along the middle of the bristol board draw a line *AB* (Fig. 2). Beginning at a point about 2 cm. from the left-hand end of the board, lay off along the upper side of *AB* a scale of centimeters in the following manner. Stand the scale on edge and make a fine mark exactly opposite each centimeter mark.

Through each dot draw a line 1 cm. long at right angles to *AB* and number them as in Fig. 2. This is called the *scale*. Upon it write the word "scale" distinctly.

Prolong the line marked 0 below *AB*. From this line along the under side of *AB* lay off a scale of 10 divisions, each division being 9 mm. long. This is called the *vernier*. Upon it write the word "vernier" distinctly. Draw *CD* one half centimeter to the left of the 0 line.

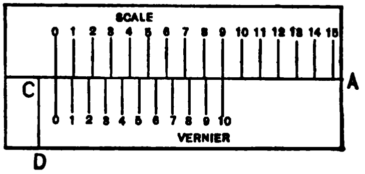


FIG. 2.—Pasteboard Vernier Caliper

With a sharp knife or shears cut carefully and smoothly along *CD* and *CA*.

Problem.—(2) To read a vernier caliper.

Set the 1 lines opposite one another. How far are the jaws separated? In like manner, how far are the jaws separated when the 2, 3, 4, 5, etc., lines on the vernier coincide with the 2, 3, 4, 5, etc., lines on the scale? Similarly when the 3 line on the vernier coincides with the 5 line on the scale? With the 8 line on the scale? In general, how does the separation of the jaws of the caliper compare with the separation of the zeros of scale and vernier?

Application.—Write out a rule for measuring to a tenth of a centimeter.

THE VOLUME OF A CYLINDER

Problem.—To measure the diameter and length of a cylinder, using a vernier caliper, and to compute its volume.

Apparatus.—A metal cylinder with true ends; a vernier caliper (Fig. 3).

Experiment.—Notice that the divisions on the vernier are not numbered, but that when the jaws are closed the 0 of the scale should coincide with the 0 of the vernier. If it does not coincide, find the correction to be applied to each reading. How many divisions on the scale are equal to the divided (ruled) portion of the vernier? Will the separation of the jaws in this instrument be read in the same manner as in the homemade instrument? In other words the zero line of the vernier is an index (pointer) whose position on the scale shows the separation of the jaws of the caliper. The vernier scale assists us in finding the position of this index on the scale.

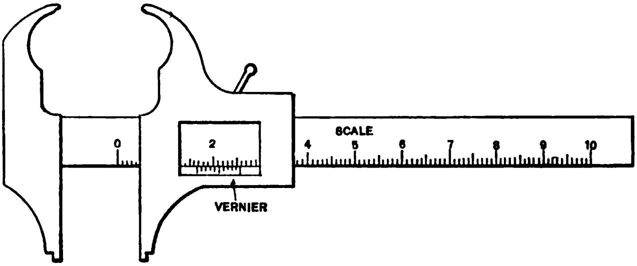


FIG. 3. — Jeweler's Caliper

Measure the diameter of the cylinder in six different places. Measure its length three times. Enter results in a tabular form. Show to the instructor before proceeding further.

The volume of the cylinder is $\pi r^2 h$. Calculate the volume of this cylinder. You will obtain several decimal places in the answer. How many of them are significant, *i.e.* represent actual accuracy of measurement? Retain one doubtful figure only. Consult the instructor.

Application. — Make a sketch of a vernier which would read to one sixth of a scale division instead of one tenth.

Give a general rule for constructing a vernier which shall read to any desired fraction of a scale division.

WEIGHT AND DENSITY OF A CYLINDER

Problem. — To find the weight of the same cylinder whose volume was calculated in the preceding exercise.

Apparatus. — The same brass cylinder whose volume has been measured; platform balances (Fig. 4); equal arm balances (Fig. 5); horn pan balances (apothecaries' scale, Fig. 6); sets of weights; pincers for handling brass or aluminum weights; spring balances.

Precautions to be observed in weighing with any kind of balance.

Before beginning to weigh be sure —

(1) that the pans of the balance are clean,

(2) that the beam swings freely,

(3) that the balance when in its position of rest reads zero, or, if swinging, that the pointer makes equal excursions on the two sides of the zero. *Ask the instructor how to correct any error of zero reading.*

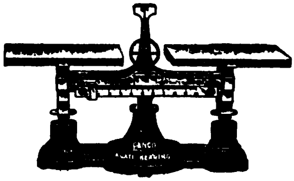


FIG. 4. — Platform Balances

Handle brass or aluminum weights with pincers. Iron weights may sometimes touch the hand, brass weights never. Never use weights from one set with those of another set. In weighing always place the object to be weighed on left-hand pan, weights on right. Always try the largest weights first.

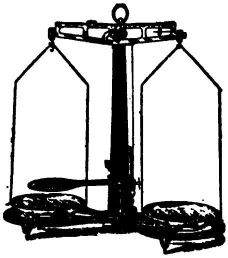


FIG. 5. — Equal Arm Balances

Experiment. — Place cylinder on left-hand pan of balance. Counterbalance with weights. *Do not borrow weights from your neighbor.* In the case of the platform balance and the equal arm balance respectively, weigh fractional parts of 5 and 10 gm. with the slider. Enter the weights used in a vertical column and add. Repeat this process on platform *or* equal arm balance *and* on horn pan balance. Check results by weighing with the spring balance. Enter result in a tabular form. Are these weighings correct? Why not?

From the mass (weight) as found in this exercise and from the volume as found in the preceding exercise find in grams per cubic centimeter the density of the material of which this cylinder is made.

Should all the results of the class be the same or nearly the same? Explain why.

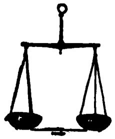


FIG. 6. — Horn Pan Balances

Application. — What is the density of a piece of wood whose weight is 50 gm. and whose dimensions are 3 × 5 × 10 cm.?

What is the density in pounds per cubic foot of a stone which weighs 800 lb. and whose dimensions are 2 × 3 × 1 ft.?

Why are densities in pounds per cubic foot about 62.5 times as great as densities in grams per cubic centimeter?

VOLUME AND DENSITY OF AN IRREGULAR SOLID

Problem. — To find the volume and density of an irregular solid.

Apparatus. — Any irregular solid such as a piece of gas pipe, glass tubing, or rod; balances; weights; a cylinder graduate.

Experiment. — Weigh the solid on two or three forms of balance. Enter results in a tabular form.

Put some water in the graduate. Read the volume of water taken as closely as possible, estimating tenths of the smallest division on the graduate. In making such a reading always read to the *bottom* of the curved surface of the water (Fig. 7).

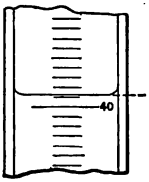


FIG. 7. — How to read a Graduate

Incline the graduate and slide the solid carefully down the side so that it is entirely submerged (Fig. 8); *or* lower the cylinder by a thread. Read the new water level; *i.e.* to the under side of the curved surface. Repeat with different amounts of water at least three times. Enter results in a tabular form. For the best value of the volume take the average. Why?

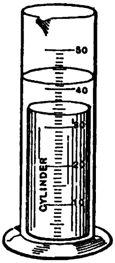


FIG. 8. — Graduate and Cylinder

From the values of the mass and volume thus obtained calculate the density of the solid.

Would this method be suitable for a solid that absorbed water or was soluble in water? Why not?

Application. — A piece of nickel-plated ware weighs 240 gm. and displaces about 28 cc. of water. Was the nickel plated on iron or brass? (Density cast iron in grams per cubic centimeter, 7.1; density brass, 8.5.)

THE SLIDE RULE (Review Experiment)

Problem. — To learn to multiply and divide, square numbers, and extract square roots by means of a slide rule.

Apparatus. — A slide or calculating rule.

Description. — The slide rule (Fig. 9) consists of three parts — a body or stock carrying two fixed scales, *A* and *D*; a slide also carrying two scales *B* and *C*; and usually a runner carrying a fine line. The *A* and *B* scales are exactly alike. They begin at 1 and extend to 100, the space corresponding to successive numbers always decreasing. This is a consequence of the fact that the *distances on these scales represent logarithms.* The spaces corresponding to a given number are just twice as long on the *A* and *B* scales, as on the *C* and *D* scales. The 1 line of each scale is called the "index."

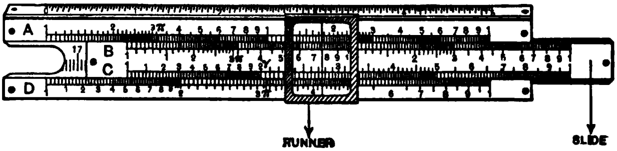


FIG. 9. — The Slide Rule

Since the common logarithm of a number is the exponent of the power to which 10 must be raised to equal the number, the spaces on these scales correspond to exponents. To multiply two numbers referred to the same base, their exponents are added; to divide, they are subtracted; to extract the square root, they are divided by two; to raise to the second power, they are multiplied by two. The construction of the rule makes it very easy to perform these four operations.

The following rules will be at once evident.

Rule for Multiplication. — Set the index of the *B* scale to one factor on the *A* scale. Over the other factor on the *B* scale read the product on *A*. Or, set the index of *C* to one factor on *D*. Under the other factor on *C* read the product on *D*.

Rule for Division. — Set the divisor on *B* under the dividend on *A* and read the quotient on *A* over the index of *B*.

Rule for Squaring a Number. — Set the index of the runner to the given number on *D* and read off the required square exactly opposite on *A*.

Rule for Square Root. — Set the index of the runner to the given number on *A* and read off the required root exactly opposite on *D*.

In all cases the decimal point must be carefully located according to the rules of arithmetic.

Application. — Solve the following problems by the slide rule. Check the result by arithmetical calculation.

$4 \times 2 =$ $5 \times 3 =$ $6 \times 8 =$ $18 \times 5 =$ $18 \times 40 =$

$6/3 =$ $28/7 =$ $65/13 =$ $400/20 =$ $17/9 =$

$5^2 =$ $8^2 =$ $15^2 =$ $1.9^2 =$

$\sqrt{49} =$ $\sqrt{73} =$ $\sqrt{11} =$ $\sqrt{28} =$

Find the area (πr^2) of a circle whose radius is 3.

Find the volume ($\pi r^2 h$) of a cylinder whose radius is 2 and whose altitude is 5.

PARALLELOGRAM OF FORCES

Problem. — To find the relation between two concurrent forces not in the same straight line and their resultant.

Apparatus. — Three spring balances, preferably weighing to 2000 gm.; small key or curtain ring; string; nails or pegs; hard, sharp pencil; ruler.

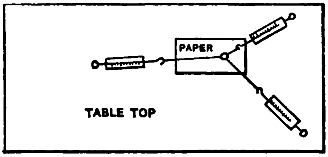


FIG. 10. — Parallelogram of Forces

Experiment. — Number the spring balances 1, 2, 3. Take the zero correction of each while in the horizontal position. Tie three pieces of string to a ring and make a loop in each string at a convenient point. Hook the balance over the loop so that the ring and balances lie flat (Fig. 10). Fasten the rings of the balances over nails or pegs on the tables so that the readings of the balances shall lie between 500 gm. and 1800 gm. The balances should not touch the table.

Slip a sheet of paper from the notebook under the ring. Mark the direction of each of the three forces by a series of dots directly beneath each string. Read each balance. Enter each reading, + or – the zero correction of the balance, beside the corresponding set of dots thus, 875 + 15, or 1250 – 25. Change the readings of the balances by changing the position of the knot in one or more of the strings and repeat the operation. Enter both sets of results in a tabular form.

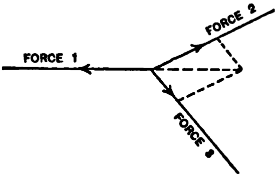


FIG. 11. — Concurrent Forces

Connect each set of dots by a straight line. What does its direction indicate? Should the three lines in each observation be concurrent, *i.e.* meet at a point? Why?

Adopt some convenient scale such as 200 gm. = 1 cm. and construct a parallelogram on any two of these lines. Is the concurrent diagonal in the same straight line with the third line? Should it be? Measure this diagonal and compare the number of grams it represents with the third force. Are they equal? Should they be equal? Proceed in the same manner for the other sets of forces. Are these forces in equilibrium? When are three non-parallel forces in equilibrium?

Is the following conclusion justified? If the adjacent sides of a parallelogram are constructed so as to represent two concurrent forces, the concurrent diagonal (the one passing through the same vertex) represents their resultant. This statement is known as the principle of the *parallelogram of forces.* Is it a necessary consequence if Newton's Second Law is correct? Explain why.

Is the algebraic sum of two of the forces equal to the third force? Why not?

Application. — **When is the algebraic sum of two forces equal to their resultant?**

Three forces are in equilibrium. One is a horizontal force of 50 gm. and the other a vertical force of 15 gm. Find the value of their resultant.

PARALLELOGRAM OF FORCES (Review Experiment)

Problem. — **To resolve three concurrent forces into rectangular components along two axes and then to find the algebraic sum of the components.**

Apparatus. — **A board about 24 in. square; cross-section paper; thumb tacks; nails; string; small ring; three spring balances preferably reading to 2000 gm.; hard, sharp lead pencil.**

Experiment. — **Fasten the rings of the spring balances to nails and the hooks to strings looped into the small ring so that the spring balances lie flat. Each balance should read more than 900 gm.**

Draw a pair of axes at right angles through the center of a sheet of cross-section paper. Fasten the paper under the ring so that the intersection of the axes corresponds to the point at which the lines representing the forces meet.

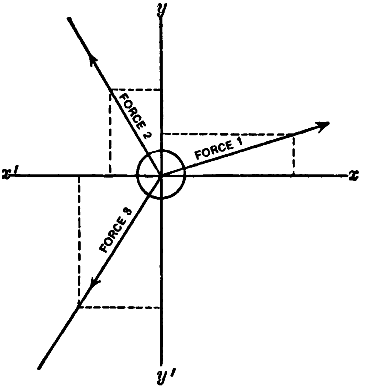


Fig. 12. — Resolution into Rectangular Components

Very carefully mark several points directly under each string. Enter the value of the force (scale reading ± zero correction) opposite the line representing the force. Remove the balances and strings and draw the lines representing the forces. Along each line lay off a distance proportional to the forces.

Resolve each force into a pair of rectangular components parallel to the axes; *i.e.* drop perpendiculars upon the axes from the extremities of the lines representing the forces (Fig. 12). Find the algebraic sum of all the components parallel to the X axis. Is the sum zero within the experimental error? Find the algebraic sum of all the components parallel to the Y axis. Is the sum again zero?

Repeat the experiment with other forces and calculate the algebraic sum of the components as before.

Make a general statement concerning the relations existing among the components of forces in equilibrium.

Application. — A trolley wire is hung from guy wires running to posts at the side of the road. How does the tension in the guy wires compare with the weight of the trolley wire they support?

RESOLUTION OF FORCES (Review Experiment)

Problem. — To resolve a force into two components at right angles when one of them is known.

Apparatus. — Several heavy weights, a spring balance reading to 2000 gm., a card, a rod with square ends about 1 ft. long, a ruler.

Experiment. — Arrange the apparatus as shown in Fig. 13. The cord attached to one end of the spring balance is fastened to any vertical support at A. The cord attached to the other end is fastened to B. At B a heavy weight, say 1 kgm., is suspended. The rod CB is set at right angles to AC.

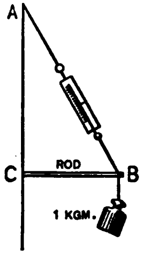


FIG. 13. — Resolution of Forces

What is the relation between the forces in the three sides of the triangle ABC and the lengths of the sides? Measure the sides AC and BC and calculate AB. What force does the length AC represent? Calculate the force represented by BC. Calculate the value of the force in AB and compare with the reading of the spring balance. Explain carefully why the calculated value and the observed value should not agree.

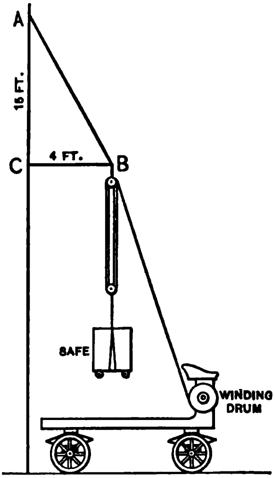


FIG. 14. — Lowering a Safe

Repeat the experiment with different lengths for AB and different weights at B. Is the force in AB increased or decreased as the angle at A decreases?

Application. — A safe weighing 4 T. (with its tackle) is lowered from a second story window to the ground. To swing it clear of the building a rigging is arranged as shown in Fig. 14. The guy rope *AB* is fastened at a point 15 ft. above *C*. The brace *BC* is 4 ft. long.

What compression must *BC* be able to stand? How great is the tension in *AB*? What is the pull in the rope passing over the block and tackle?

THE PRINCIPLE OF MOMENTS

Problem. — To find the relation between the moments of force acting on a body free to rotate about an axis when the body is in equilibrium.

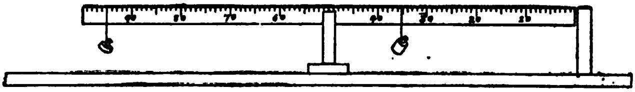


FIG. 15. — A Pivoted Meter Stick

Apparatus. — A pivoted meter stick and supports as shown (Figs. 15 and 16); some pieces of wire about No. 16; 20, 50, and 100 gm. weights; fine thread; cylinder of brass.

Experiment. — Suspend the meter stick by a nail through its 50 cm. mark. The hole should be above the center of the stick. Bring it into a horizontal position by pinching a loop of wire to the high side. Mark the horizontal position on the index bar.

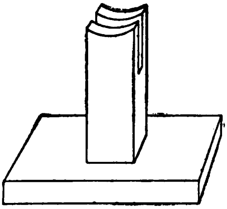


FIG. 16. — Support

By a loop of thread suspend a 50-gm. weight on the right-hand arm of the meter stick at a distance of 20, 30, or 40 cm. from the pivot. Suspend another 50-gm. weight on the left-hand arm of the stick. At what point must it hang to keep the bar in equilibrium? Are the moments of the two weights equal?

Repeat the experiment, using a 50-gm. weight on the right-hand arm of the pivoted bar, counterbalancing it by a 100-gm. weight on the left-hand side. Are the moments equal? Try various combinations of weights on the two sides of the bar at various distances from the axis. Arrange results in tabular form. The distance of the weight from the pivot is called the *lever arm.* Is it true that moment of force = weight × lever arm? For equilibrium is it always true that *moments on the left-hand side of the pivot = moments on the right-hand side?*

Left-hand Arm						Right-hand				
5	4	3	2	1	Experiment	1	2	3	4	5
					Force					
					Lever Arm					
					Moment					
					Difference					

State the principle of moments.

Application. — From these results devise a method of weighing the cylinder using only a single weight. Test the correctness of the reasoning by weighing in this same manner the cylinder used in previous exercises. Compare results with previous weighings.

A meter stick is balanced over a fulcrum. How great a weight 5 cm. from the fulcrum can balance a 200-gm. weight 40 cm. from the fulcrum ?

A fisherman catches a trout but has no scales on which to weigh it. He has however a two-foot rule and a can of beans that weighs just one pound. How can he weigh the trout?

PARALLEL FORCES

Problem. — To investigate the conditions of equilibrium for three or more parallel forces.

Apparatus. — Two spring balances reading up to 2 kgm.; meter stick; 500-gm. or 1-kgm. weights; strong thread or cord.

Experiment. — Suspend the two spring balances (Fig. 17) so that their hooks are just 80 cm. apart. Suspend the meter stick from the balances by thread or cord, attaching the cord exactly at the 10 and 90 cm. divisions on the scale. Will the balances now indicate parallel forces? Read the balances in this position and record their readings in a tabular form as the *reading with no load*, or *the zero reading*. Suspend the 1-kgm. weight from the center of the meter stick. Read the balances

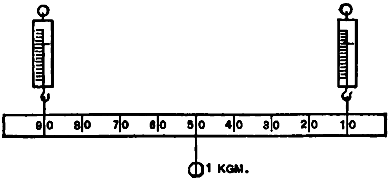


FIG. 17. — Suspended Meter Stick

again and record their exact readings in the tabular form. How does the sum of their corrected readings compare with the load; namely, with 1 kgm.? Are the readings of the balances equal? Should they be equal according to the principle of moments?

Left Hand			Trial	Right Hand		
3	2	1		1	2	3
			Reading no Load			
			Reading with Load			
			True Load			
			Lever Arm			
			Moment			
			Difference of Moments			

Hang the 1-kgm. weight successively at the 40 and 60 divisions. In each case how does the increase in load indicated by the balances compare with 1 kgm.? In each case does the 1-kgm. weight divide the distance between the points of application of the forces measured by the spring balances inversely as the forces? Should this be true according to the principle of moments? Is the resultant of the two parallel forces always equal to their algebraic sum? When three parallel forces are in equilibrium, is the algebraic sum of the forces zero? Is the algebraic sum of the moments about any axis zero?

State the rule for finding the resultant of two parallel forces.

State the rule for finding the resultant of any number of parallel forces.

Application.— Two horses are pulling along parallel lines 5 feet apart. One horse pulls 400 lb. and the other pulls 300 lb. The evener remains at right angles to the direction in which they are pulling. Where does the bolt pass through the evener?

CENTER OF GRAVITY

Problem. — To show that the total mass of a body acts as if concentrated at its center of gravity.

Apparatus. — Half a meter stick loaded at one end (Fig. 18); thread; a 10, 20, or 50 gm. weight.

Experiment. — Suspend the bar by a loop of thread so that it hangs horizontally. Why is the point thus found the center of gravity of the bar? Record the reading on the bar. Suspend any weight from the bar by a loop of string and again bring the bar to a horizontal position. Record the position of the weight and the position of the new point of suspension. Repeat, using a different weight. Weigh the bar. Calculate in each case the moments of force about any fixed point, for instance about the point of suspension. Assume in each case that the weight of the bar always acts at its center of gravity as found above.

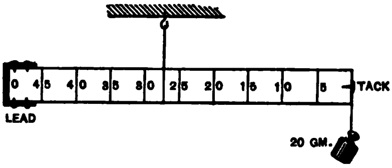


FIG. 18. — A Loaded Half-Meter Stick

Are the moments of force in each case equal within reasonable experimental error? Arrange results in tabular form so as to demonstrate this fact.

Center of Gravity of Bar is at__________ Weight of Bar________

Weight				
New Center of Gravity at				
Lever Arm of Weight				
Moment of Weight				
Moment of Bar				
Difference				

Application. — A cane thrown into the air usually rotates about some point in the cane. Why? If the cane is struck at this point, it travels without rotation. Why?

In carrying a pine telegraph pole two men take hold at the big end of the pole while one man is able to handle the smaller end. Explain why according to this experiment.

CENTER OF GRAVITY (Review Experiment)

Problem. — In a body consisting of two parts, to find how the centers of gravity of the two parts are situated with respect to the center of gravity of the whole body.

Apparatus. — Piece of cardboard about 6 in. × 8 in. of any shape, either irregular or triangular; plumb line (light thread with a weight at one end); pin; cork; clamp; ring stand; balance; weights.

Experiment. — Suspend the cardboard by a pin stuck horizontally through it into a cork held in a clamp. Enlarge the pinhole slightly, so that the card swings freely. Hang a plumb line from the same pin close to the card. Make a pencil dot at the lower edge of the card exactly under the pin. Draw the vertical line through the point of support. Does the center of gravity lie somewhere on this line? Why? In such a body as this card, does the center of gravity seek to place itself as low as possible?

Suspend the card from a different point, as before, and find a new vertical line. At what point does the center of gravity of the card lie?

Now cut the card into any two pieces. Weigh each to $\frac{1}{10}$ of a gram. Find the center of gravity of each piece in the same way that the center of gravity of the whole body was found.

Fit the two pieces accurately together, and draw a straight line joining the centers of gravity. Does the center of gravity of the whole card lie on this line?

Measure, to $\frac{1}{10}$ mm., the distances from the center of gravity of the whole card to the center of gravity of each of the pieces.

Multiply the weight of each piece by the distance from its center of gravity to the center of gravity of the whole card. Are these products nearly the same for the two pieces? Are they the moments of the parts of the card about the center of gravity? Why should they be equal?

If the line joining the centers of gravity of the pieces is considered a weightless lever with its fulcrum at the center of gravity of the whole card, and if weights equal to those of the two pieces were hung from its ends, would it be in equilibrium?

Why does this experiment indicate that the total weight of a body may be considered as concentrated at its center of gravity?

FRICTION

Problem. — An investigation of the laws of friction.

Apparatus. — A spring balance reading to 2000 gm.; a block of wood about 2 in. × 4 in. × 4 in. fitted with a screw hook or screw eye (Fig. 19); a sled of iron, copper, brass, or zinc, with one edge bent up a little; some 1 and 2 kgm. weights.

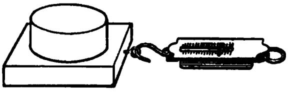


FIG. 19. — Block, Load, and Balance

Experiment. — Remove loose dust from the table top and from wooden block. Fasten balance to screw hook. Weigh the block, using the spring balance. Lay the block flat on the table. Place a load of 1 kgm. upon it and draw it uniformly along the table top. The average reading of the balance is the force of friction. Prepare a tabular form and enter the weight of the block, the weight used, the total load, the force of friction, etc. Repeat the operation with various loads.

Weight of Block__________

Experiment	Weight Added	Total Load	Force of Friction	Coefficient of Friction
1				
2				
3				
etc.				

The ratio $\frac{\text{force of friction}}{\text{total load}}$ is called the coefficient of friction. In the above instances is the coefficient of friction approximately constant? Repeat the experiment with the block on edge and with any weight. Is the coefficient of friction approximately the same? Does friction depend upon the areas in contact or upon the load?

Repeat the experiment with various weights, using the sled of metal. Is the coefficient of friction the same between wood and wood as between wood and metal? What effect has the character of the surfaces in contact on the coefficient of friction?

Application. — Engine bearings are invariably made of brass or steel on Babbitt metal. Why? What is meant by antifriction metals?

What frictional force does the ice exert on a sled weighing 50 lb. if the coefficient of friction is 0.02? Would the force of friction be the same if the sled were coasting down hill instead of on the level?

FRICTION ON AN INCLINED PLANE (Review Experiment)

Problem. — To find the coefficient of friction on an inclined plane.

Apparatus. — Wooden or pasteboard box about 4 in. square and 2 in. deep; smooth board 2 ft. or 3 ft. long; meter stick; weights.

Experiment. — Set the meter stick vertical to the table top as shown in Fig. 20. Put a 200-gm. weight in the box, place the box on the board, and raise one end of the board until the box slides uniformly down the plane. Measure *AC*, *AB*, and *BC* and enter in a tabular form.

Draw a triangle to scale as in Fig. 21. Resolve the force due to the load (*LG*) into two forces at right angles, one parallel to the board (*LK*) and one perpendicular to it (*LH*). Are the forces in this triangle proportional to the sides of the triangle? Explain why. Which one of these forces represents force on the plane? Which one the force of friction? Are the triangles *ACB* and *LKG* similar? Explain. Is the following statement correct?

$$\frac{\text{force of friction}}{\text{force on the plane}} = \frac{\text{height of plane}}{\text{base of plane}} = \text{coefficient of friction.}$$

Give reasons for your answer.

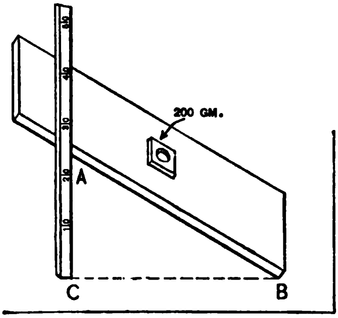


Fig. 20. — Friction on an Incline

Repeat the experiment with different loads. Draw a diagram for each experiment. Is force of friction proportional to the load? Is coefficient of friction dependent only upon the substances in contact?

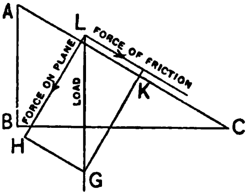


Fig. 21. — Resolution of Load

Application. — An expressman is handling a box of freight by means of an inclined plane. The plank is 16 ft. long and the end in the wagon is 3 ft. above the lower end. The box just slides down the plank. What is the coefficient of friction?

In determining coefficient of friction by this method, is it necessary to measure the weight of the load or the force of friction? Why not?

PERIODIC MOTION

Problem. — To find the period of a vibrating pendulum.

Apparatus. — Balls of wood, and lead, brass, or steel about ½ in. in diameter; thread; any suitable support; a watch with seconds hand.

Experiment. — Fasten a wooden ball to a thread about one meter long. Suspend this so that the ball shall clear the table by about an inch and so that the thread shall be as long as the support permits (Fig. 22). Set the pendulum swinging through an arc of about 2 in. Take the time of 50 round trips of the vibrating ball. Repeat twice. Enter in tabular form. Calculate in each case the time of one round trip; *i.e.* of one complete vibration. *The time of one complete vibration is the period of the vibrating body.*

KIND OF BALL	LENGTH	TIME OF 50 VIBRATIONS	PERIOD

Measure the distance from the point of support of the string to the middle of the ball. This is the *length* of the pendulum.

Replace the wooden ball by one of metal. Make the pendulum the same length as before. In similar manner take the time of 50 vibrations.

Does a pendulum of the same length swinging through the same arc always have the same period? Does the mass or material of the pendulum affect the period?

Change the length of the pendulum and time it again. Does a change in length of a pendulum affect the period? How does the period change as the length of the pendulum increases; as it decreases?

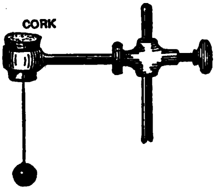


FIG. 22. — Suspending a Pendulum

Application. — The flywheel of an engine makes 75 revolutions per minute. What is its period?

A pendulum clock gains time. How may it be made to keep correct time?

THE PENDULUM

Problem. — (1) To find the relation between the period of a pendulum and its length.

(2) To calculate g, the acceleration due to gravity.

Apparatus. — Thread; a ball about $\frac{1}{2}$ in. in diameter; a suitable support; a watch with seconds hand.

Experiment. — Suspend the ball as a pendulum, making the length of the pendulum (the distance from the point of support to the middle of the ball) as nearly 81 cm. as possible. Take the time of 50 complete vibrations over a small arc. Enter results in a tabular form. Change the length successively to 64, 49, and 36 cm. Compute the respective periods. Is the period of a pendulum proportional to the square root of its length; *i.e.* is $T \propto \sqrt{l}$?

LENGTH l	TIME OF 50 VIBRATIONS	PERIOD T	$\frac{\text{PERIOD}}{\sqrt{\text{LENGTH}}} = \frac{T}{\sqrt{l}}$

Is it also true that period is inversely proportional to the square root of the acceleration due to gravity; *i.e.* is $T \propto \frac{l}{\sqrt{g}}$? The period of a pendulum may always be calculated by aid of the relation, $T = 2\pi\sqrt{\frac{l}{g}}$, if the length l, and g are known. If T and l are known, can g be computed?

From your observations of l and calculations of T, compute values for the acceleration due to gravity at this place.

Give some of the reasons why your value for g is not the correct one.

Application. — Describe the simplest apparatus that would be necessary to obtain the data required to calculate the value of the acceleration due to gravity at the north pole; on a high mountain.

A block of stone, just swung clear of the ground by a derrick at the top of a high building, is observed to make one complete swing in 15 sec. How high is the building?

WORK ON AN INCLINED PLANE

Problem. — To show that the work done in lifting a body through a given height is independent of the path of the body.

Apparatus. — A board which may be set as an inclined plane (Fig. 23); a spring balance graduated to 2000 gm.; a small car; heavy weights that will fit into the car.

Experiment. — Using the spring balance weigh the car and, if necessary, the heavy weights to be used. Set the board so that it makes an angle between 30 and 45 degrees with the floor.

Hook the spring balance to the car and draw it slowly but uniformly up the incline, always keeping the pull parallel to the plane. Read the average force required. Repeat, allowing the car to go down the incline. The average of these readings may be taken as the force required to move a frictionless car. Measure the length and height of the plane. Calculate the work required to move a frictionless car from one end of the plane to the other when the force is parallel to the plane. Also calculate the work required to lift the car straight up the height of the plane. Compare these two values. Are they equal within reasonable experimental error? If so, is the work done independent of the path?

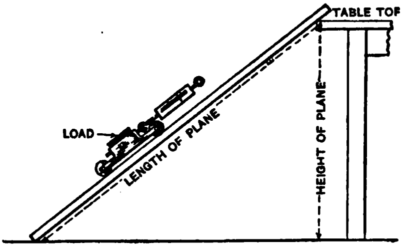


FIG. 23. — Inclined Plane

Repeat the experiment twice, using different loads in the car each time. Arrange results in a tabular form.

Length Plane__________ Height Plane__________

Weight Car__________ Weight (1)__________ Weight (2)__________

EXPERIMENT	1	2	3
Load — car and weight			
Reading up Plane			
Reading down Plane			
Average			
Work along Plane			
Work on Straight Lift			
Difference			

In each case is the ratio of the force exerted to the load equal to the ratio of the height of the plane to the length?

Application. — Does the man who uses an inclined plane to load a heavy box do less work thereby?

An engine pulls a train weighing 2000 T. up an incline 10 ft. high. Does it do any less work than by lifting 2000 T. straight up?

THE PULLEY

Problem. — To find the mechanical advantage and efficiency of a system of pulleys.

Apparatus. — At least one each, single and double pulley; two spring balances reading to 2000 gm.; cord; heavy iron weights.

Experiment. — Suspend the single pulley from a support and pass a cord over it having a heavy weight on one end. Measure the pull on the other end with the spring balance. Compare the reading of the balance (effort) with the weight (resistance). *The quotient* $\frac{\text{resistance}}{\text{effort}}$ *is called the mechanical advantage.* What is the value of the mechanical advantage of a single fixed pulley?

Suspend one of the spring balances and attach one end of the cord to its hook (Fig. 24). Suspend the pulley over the cord and fasten the second spring balance to the free end of the cord. Hang a heavy weight from the pulley. Compare the readings of the spring balances when both are pulling straight up. Does each balance carry half the weight? Is the mechanical advantage of a single movable pulley 2? Why?

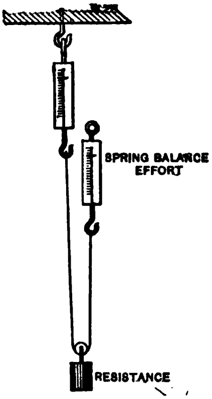


FIG. 24. — How many parts of the cord support the weight?

Suspend one of the double pulleys and rig a cord through it and also through the second pulley. Hang a heavy weight to the second pulley. Attach a spring balance to the free end of the cord. Is the pull in the balance about one fourth the load when there are four parts of the cord between the pulleys, about one third when there are three parts, etc.? State concisely a rule for finding the mechanical advantage of a system of pulleys in which only one cord is used.

Draw the spring balance so that the resistance moves through about 10 cm. How far does the effort move? Compare the work done by the effort with the work done on the resistance. Why are they not equal? The efficiency of any machine is the ratio, $\frac{\text{useful work}}{\text{total work}}$. Calculate the efficiency of the set of pulleys you are using.

Application. — A 10-T. stone is to be lifted by a system of pulleys operated by an engine that can exert a pull of 8000 lb. Assuming the efficiency of the system to be 60%, what is the least number of sheaves in the pulleys? Draw a diagram.

ELASTICITY

Problem. — To find how the length of a spiral spring changes with the stretching force.

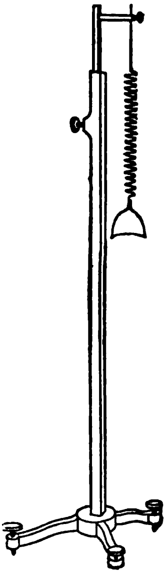


FIG. 25. — Spiral Spring

Apparatus. — A spiral spring made of about No. 18 spring brass wire; a support; a meter stick; a scale pan; a set of weights from 10 gm. to 200 gm.

Experiment. — Suspend the spiral spring near the upright meter stick (Fig. 25). Attach the scale pan to it and add a weight heavy enough to stretch the spring. Read carefully on the meter stick the position of the pan. Call this the zero reading.

Add a 10-gm. weight and read the new position. Similarly add weights and take readings until the spring has been stretched to twice its original length. Record these readings in a tabular form, leaving two columns in which to enter "change of load" and "change of length."

What relation do your results show between the change of length and the stretching force? This relation is known as Hooke's Law. State it.

LOAD	READING	CHANGE OF LOAD	CHANGE OF LENGTH

Application. — Explain how to make a spring balance to weigh from 0 to 2000 gm. How would the scale opposite the pointer be constructed?

SPECIFIC GRAVITY BY ARCHIMEDES' PRINCIPLE

Problem. — To apply the principle of Archimedes to finding the specific gravity of a solid.

Apparatus. — A metal cylinder; pieces of iron, aluminum, etc.; a spring balance weighing to 250 gm. or preferably an equal arm or trip balance (Fig. 26); a glass battery jar; thread.

Experiment. — Weigh the cylinder carefully on the spring balance and compare this weight with that previously found. Suspend the cylinder by a thread in such a way that it is entirely under the surface of water and weigh again. What volume of water does the cylinder displace? How much does this water weigh? Compare the decrease in weight of the cylinder with the weight of the water displaced. State Archimedes' principle. Do the results here obtained agree with Archimedes' principle?

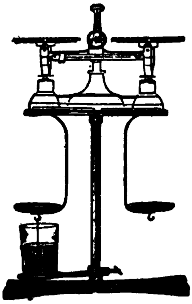


FIG. 26.—Trip Balance for Specific Gravity

In similar manner weigh the pieces of iron and aluminum. Account in each case for the decrease in weight. Arrange results in a tabular form.

Define specific gravity. From the above results compute the specific gravity of brass, iron, and aluminum.

Measure the dimensions of a wooden block and compute its volume. Weigh it. Place in water. Why does it float? What weight of water does it displace?

Give a concise statement embodying your observations on solids more and less dense than water when placed in water.

Application. — A jeweler is offered a piece of a silvery metal weighing 500 gm., and purporting to be platinum, for $50. Platinum is worth about 80¢ per gram. How can he determine whether or not a piece of tin is being sold to him for platinum?

Why does an empty bottle float, while, when filled with water, it will sink?

THE SPECIFIC GRAVITY OF A LIGHT BODY

Problem. — To find the specific gravity of a solid that floats in water.

Apparatus. — Blocks of pine, cherry, oak, etc.; trip balance, equal arm balance, or spring balance weighing to 250 gm.; battery jar; sinker; thread.

Experiment. — Suspend the sinker in water and find its weight in that position. Weigh the block in air. Tie the sinker to the block in such a way that both are entirely submerged and weigh the combination in that position. Calculate the loss of weight. This will be due to the block alone. Why is total loss of weight = buoyant force on block = weight of water displaced by block?

Calculate the specific gravity of the block.

Repeat with blocks of other varieties of wood.

Record results thus:

SUBSTANCE	WEIGHT OF			BUOYANT FORCE	SPECIFIC GRAVITY
	Block in Air	Sinker in Water	Both in Water		

Application. — 1. Teak wood is more dense than water, yet it is rafted to market. It grows near thickets of bamboo. Devise a plan for floating it to its destination.

2. A piece of wood which weighs 70 gm. in air is attached to a piece of lead that weighs 100 gm. in water and the two together weigh 50 gm. in water. Find the specific gravity of the wood. What kind of wood might it be?

3. Two blocks of wood are painted black. Devise an experiment to find out whether the blocks are mahogany and pine respectively.

SPECIFIC GRAVITY OF A LIQUID

Problem. — To find the specific gravity of a liquid by weighing a solid in it and in water.

Apparatus. — Metal or glass cylinder; thread; equal arm or trip balance arranged for specific gravity, or spring balances reading to 250 gm.; battery jars; water; solutions of copper sulphate (blue), potassium bichromate (red), potassium permanganate (purple). These solutions may be made up of any convenient strength. The specific gravity will vary accordingly.

Experiment. — Weigh the cylinder in air, then weigh in water. Wipe dry. Weigh in copper sulphate (blue) solution. How may the weights of equal volumes of water and of copper sulphate be found? What do the losses of weight in the two solutions represent? How may the specific gravity of copper sulphate be found? Calculate.

Rinse the cylinder and wipe dry. Why? Repeat the experiment using successively solutions of potassium bichromate (red) and potassium permanganate (purple). Calculate the specific gravities.

Enter results in a tabular form thus:

LIQUID	WEIGHT OF CYLINDER IN			LOSS OF WEIGHT IN		SPECIFIC GRAVITY OF LIQUID
	Air	Water	Liquid	Water	Liquid	

Application. — 1. Using a common spring balance and an iron nut, how could the specific gravity of gasoline be determined? Would the result be sufficiently accurate to tell whether you had 68° or 76° gasoline?

2. Should a glass or brass cylinder be used in determining the specific gravity of nitric acid? Why?

3. A piece of glass weighs 100 gm. in air and 60 gm. in water. What is the specific gravity of glass?

4. How would a determination of its specific gravity determine whether milk had been watered? (Specific gravity of milk ranges from 1.028 to 1.035.)

HARE'S METHOD

Problem. — To find the specific gravity of a liquid by the method of balancing columns (Hare's method).

Apparatus. — A Hare's apparatus (Fig. 27); beakers; pinch clamp; solutions of copper sulphate, potassium bichromate, potassium permanganate.

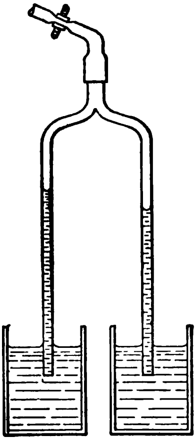


FIG. 27. — Hare's Apparatus

Experiment. — Place distilled water in one beaker and the liquid whose specific gravity is to be determined in the other. Why do the liquids in the tubes stand higher than the liquid in the beaker outside? To correct for this difference of level the apparent height of the columns must be decreased by the amount by which the liquids stand higher in the tubes than in the beakers. Read the heights of the liquids in the tubes and in the beakers. The difference is the correction which must be applied to each reading.

Draw the liquids up the tubes within three or four inches of the bend of the tubes. Be very careful not to draw the liquids too high. Why? Be sure that the apparatus does not leak air. How may a leak be detected? Close any leak before proceeding farther.

Read and record the length of each liquid column.

TRIAL	1	2	3	4	5
Top of water column at					
Water in beaker at					
Difference					
Correction					
True length of water column					
Top of liquid column at					
Liquid in beaker at					
Difference					
Correction					
True length of liquid column					
Specific Gravity					

Allow the liquid to drop three or four inches and read again. Repeat readings at intervals of three or four inches several times. Enter results in the tabular form.

Calculate the specific gravity of the liquid by dividing the length of the water column by the length of the liquid column. Why is the specific gravity thus calculated? Explain.

Application. — Two tubes lead downward from a tank of air at atmospheric pressure. One of them dips into water and the other into mercury. A vacuum pump is attached to the tank and the water rises 18 ft. How high has the mercury risen? The specific gravity of mercury is 13.6.

What relation exists between the forces acting on the two liquids?

What relation exists between the height to which the liquid rises and the density of the liquid?

SPECIFIC GRAVITY BOTTLE

Problem. — To find the specific gravity of a liquid, using a specific gravity bottle.

Apparatus. — Balance; specific gravity bottle; solutions whose specific gravity is to be determined.

Experiment. — Weigh the specific gravity bottle carefully. Just fill it with water and weigh again. Empty the bottle and dry it thoroughly. Fill with the liquid whose specific gravity is desired and weigh again. Compute the weights of equal volumes of the liquid and water from these observations. Calculate the specific gravity.

Application. — A specific gravity bottle weighs 10.5 gm. Filled with water it weighs 25.5 gm. Filled with mercury it weighs 220.0 gm. What is the specific gravity of mercury?

HYDROMETER

Problem. — To find the specific gravity of a solution by a hydrometer.

Apparatus. — A hydrometer and jar.

Experiment. — Float the hydrometer in the liquid and read the specific gravity of the liquid on the stem.

Explain why and how such an instrument gives specific gravity. Must the stem be uniform in diameter? Why?

Why is the diameter of the stem made small?

Application. — How is the specific gravity of the acid in a storage battery tested?

How can the strength of photographic solutions be tested by the hydrometer?

What is a lactometer? What does it tell about the quality of milk?

SURFACE TENSION

Problem. — To observe and explain some of the phenomena of surface tension.

Apparatus. — Small greased needle; glass; water; needle lifter (Fig. 28); pan at least 8 in. across; wooden toothpicks; soap; soap solution; wire frames as in Fig. 29; camphor gum; vaseline.

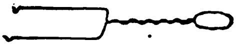


Fig. 28. — Needle Lifter

Experiment. — Grease a small needle and carefully lay it on the surface of some water. Its specific gravity is almost 8. Why does it not sink?

Float two toothpicks parallel and about an inch apart in the pan of water. Drop a tiny shaving of soap between them. Repeat until you are sure whether they go together or apart. Why do they pull apart? Does the soap weaken or strengthen the surface tension of the liquid between the sticks? Repeat, dropping a little alcohol between the sticks. Does alcohol increase or diminish the surface tension? Would you expect all liquid surfaces to exert the same tension?

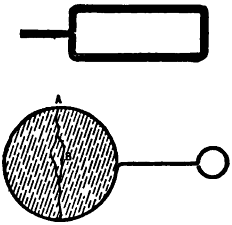


Fig. 29. — Wire Frames

Drop a small bit of camphor gum on the surface of some clean water. What is the source of the force that produces the motion?

Into the round wire frame tie a loop of thread (Fig. 29). Dip the frame into a glass of soap solution and get a film so that the loop floats in the film. Break the film inside the loop with a pencil point. Explain why the hole in the film assumes a circular shape. Has the area of the soap film become as small as possible?

Get a soap film on the rectangular frame (Fig. 29). Lay a piece of light wire across the film. Break the film on one side of the wire. Explain the motion of the piece of wire.

Try the effect of a drop of oil on the surface of water in a glass.

Application. — Why is a raindrop spherical?

Why can water be poured down a glass rod as though down a funnel? Can the same experiment be performed with mercury? Why not?

Why is oil used to calm waves?

How might surface tension be measured?

CAPILLARITY

Problem. — To observe and explain some of the phenomena of capillarity.

Apparatus. — Glass tubes of various diameters; water; mercury.

Experiment. — Dip a glass tube into water. Does the water wet the tube? When the particles of two unlike substances stick together as in the case of water and glass, the phenomenon is called *adhesion*. The force that holds together the particles of a single substance is called *cohesion*. Which is greater, the cohesion of water particles or the adhesion of glass and water? What pulls the water up the sides of the glass? Does the water stand at the same level inside the tube as outside? Is this a violation of the principle that water seeks its level? Why not? Describe clearly the forces that pull the water up the tube.

Set several tubes of different diameters upright in water. In which one does water rise highest? Should that be the case? What is the derivation of the term *capillarity*?

Repeat the same experiments, using mercury instead of water. Does mercury wet the glass? Which is greater — the cohesion of mercury particles or the adhesion of mercury and glass?

Application. — What is always the shape of the water surface in a capillary tube?

What allowance should be made for capillarity in reading the barometer or the height of the liquid in a Hare's apparatus? Why?

How does oil rise in the wick of a lamp?

How does moisture pass through the soil?

How may a piece of string be used as a siphon?

Why not use capillarity to produce a perpetual motion?

DENSITY OF AIR

Problem. — To find the weight of a known volume of air and to compute the density of air.

Apparatus. — Equal arm balances; burnt-out electric light bulb; blowpipe; candle; funnel with end drawn out to a slim point.

Experiment. — Weigh an electric light bulb very carefully. Direct a blowpipe flame against it until the glass softens and the bulb bursts inward. Weigh again very carefully. What does the gain in weight represent?

Insert a very slim funnel into the hole and fill carefully with water. Weigh roughly to the nearest gram. How may the volume of the bulb be computed? Calculate the density of air in grams per cubic centimeter; in grams per cubic meter.

Application. — Measure the dimensions of the room in meters and calculate the weight of air in the room. (1 l. of air weighs 1.203 gm. at 0° C. and normal pressure, and about 1.20 gm. at 20° C.)

Assuming a homogeneous atmosphere 2 mi. deep, calculate the total weight of the earth's atmosphere. The radius of the earth may be taken as 4000 mi. (1 cu. ft. of air weighs in the neighborhood of 0.08 lb.)

Calculate also in metric units, taking the density of air as above and the circumference of the earth as about 40,000,000 m.

THE BAROMETER

Problem. — To observe the construction and to explain the action of a mercurial barometer.

Apparatus. — A laboratory barometer; a tube about 36 in. long and $\frac{3}{8}$ in. outside diameter sealed at one end, another similar tube about 24 in. long; mercury; meter stick; dish to hold mercury.

Experiment. — Fill the shorter tube with mercury. If air bubbles stick to the walls of the tube, they may be collected by moving a large bubble of air from one end of the tube to the other. Completely fill the tube with mercury. Close the open end with the finger and invert in a dish of mercury. Attach to a support and allow to stand. Does the mercury still completely fill the tube? What supports this column of mercury?

Repeat with the longer tube. Does this tube remain completely filled when inverted in the dish of mercury? Why not? What supports this column of mercury? Measure the height of the mercury column in the longer tube. Incline the tube. Does the vertical height of the column remain the same? Why?

Read the barometer. Compare the readings. Explain why they are not quite the same. Admit a small bubble of air into the longer tube. Why does the mercury drop? What would be the effect upon the readings of a barometer if all the air bubbles had not been removed before the tube was inverted? Why is the mercury in a good barometer always boiled before inverting the tube?

Describe with a sketch the construction of the laboratory barometer. What precautions have been taken to avoid inaccurate readings? Describe clearly just how to take a reading of the barometer.

Application. — Calculate the weight of a column of mercury one square centimeter in cross section and as high as is shown by the reading of the barometer. This is the force per square centimeter exerted by the atmosphere. The specific gravity of mercury is 13.6.

Express this number in pounds per square inch.

THE LAW OF BOYLE

Problem. — To observe the relation between the volume of a given mass of air and the pressure upon it, the temperature remaining unchanged.

Apparatus. — A U-tube with closed arm about 12 in. in length and an open arm about 42 in. in length (Fig. 30); or an apparatus as shown in Fig. 31, consisting of two tubes connected by a piece of pressure tubing and filled with mercury about halfway up the tubes, — one tube is open and the other is closed by a stopcock; a suitable support; a meter stick; mercury.

Experiment. — If apparatus shown in Fig. 31 is used, mercury does not have to be handled by the student. The level of the mercury is changed by simply shifting the positions of the tubes on the meter stick. If the apparatus shown in Fig. 30 is used, pour mercury into the upright tube until it stands about an inch high in each arm of the tube. It may be necessary to tilt the tube so as to allow air to escape from the closed end. Read very carefully the length of the imprisoned air column. Is the tube nearly enough uniform in diameter so that we may regard the volume of the tube as proportional to its length? What is the pressure on the imprisoned air when the mercury stands at the same height in both arms of the tube? Is it barometric pressure? Why? Read the barometer and record the reading.

Pour mercury into the long arm of the tube until the difference in the level of the mercury surfaces is about 5 cm. Again find the length of the imprisoned air column. What is now the pressure upon it? Record observations under the following heads:

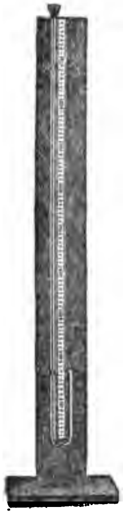


FIG. 30.—Boyle's Apparatus

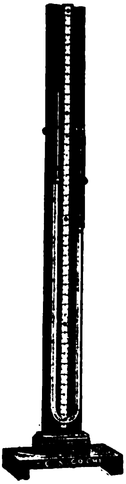


FIG. 31.—Apparatus for verifying Boyle's Law

Barometer Reading ________

DIFFERENCE IN LEVEL	TOTAL PRESSURE	LENGTH AIR COLUMN	PRESSURE × LENGTH

Why not allow the hand to touch the short arm of the apparatus? What effect does heating have on air?

Repeat the pouring in of mercury so as to change the level each time about 5 cm. until about fifteen observations have been taken. Compare the numbers in the column headed "Pressure × Length." Is the result constant within reasonable error?

State Boyle's Law. Is this law true for other gases than air?

Does this law indicate that matter in all gases is in the same condition?

Application. — Oxygen is purchased by dentists in steel tanks whose capacity is about 3 qt., and which are said to contain 40 gal. of oxygen. Calculate the pressure inside a full tank: (1) in atmospheres, (2) in pounds per square inch, (3) in grams per square centimeter. Explain.

WAVES IN THE SURFACE OF WATER

Problem. — (*a*) To show that the speed of a water wave depends on the depth of the water.

Apparatus. — Wave trough (Fig. 32) approximately 5 ft. long (it is best to have it made exactly 150 cm. long), 6 in. deep, and 6 in. wide, having at least one glass side; meter stick; watch with seconds hand; wooden paddle, not quite as wide as the trough; block of wood 2 in. × 2 in., and almost as long as the trough is wide, with a handle 6 in. or 8 in. long set into one side.

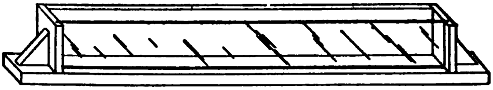


FIG. 32. — Wave Trough

Experiment. — Set the trough level and cover the bottom about 4 cm. deep with water. Set the paddle vertically about 8 in. from one end of the trough and start a wave by drawing the paddle to the end of the trough. Observe the time of six round trips of the wave. It is easier not to follow the wave along the trough, but instead to observe the rise and fall of the water at one end. Measure the length of the trough. How far has the wave traveled in the observed time? Calculate the speed of the wave motion. Arrange these results in tabular form.

Length of Trough ________. Distance of One Round Trip ________.

TRIAL	DEPTH OF WATER	TIME OF SIX ROUND TRIPS	DISTANCE TRAVELED	SPEED OF WAVE
1				
2				
3				
etc.				

Add water to the trough until the water is 5 cm. deep. Again time six round trips and calculate the speed of the wave motion as before. Repeat with depths of 6, 7, and 8 cm. of water.

How does the speed change as the depth of the water increases? Is the speed *proportional* to the depth? If so, what would be the speed after the depth had been doubled?

Application. — Why does a water wave heap up and finally break as it nears the shore? Why do the crests of waves near shore always appear to be nearly parallel to the shore?

Problem. — (*b*) To observe and describe the phenomena of stationary waves.

Experiment. — Run water into the wave trough until it is about 6 cm. deep. Lay a block of wood on the water at one end of the trough. As it is pushed down, it sets up a wave which runs to farther end of the trough and is reflected. The wave about to reach the end of the trough is the *incident wave.* After being sent back from the end, it is a *reflected wave.* Raise and lower the block periodically at such a rate that the waves which are the resultant of these two trains of waves traveling in opposite directions do not travel at all, but simply "seesaw," with no apparent backward and forward motion. These are **stationary waves.** When two waves meet crest to crest (or in the same phase), the resultant wave is larger than either. When they meet crest to trough (or in opposite phase), their resultant is less than either.

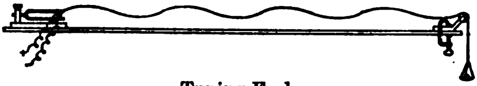
What relation exists between incident and reflected waves when stationary waves are produced?

TRANSVERSE WAVES IN STRETCHED STRINGS

Problem. — To study forced vibrations, transverse and stationary waves, and to observe how the speed of a wave motion in a string depends upon the tension and mass per unit length of the string.

Apparatus. — An electrically driven tuning fork (Fig. 33) of about 50 vibrations per second (an ordinary electric doorbell with the bell removed makes a very satisfactory substitute for the tuning fork; attach the string directly to the clapper); four-strand darning cotton; a set of weights; a pulley with good bearings; supports; batteries; meter stick.

Experiment. — Set up the tuning fork as shown in the diagram (Fig. 33) and attach to one prong a single strand of darning cotton. Let the free end of the cord hang loosely over a pulley and attach to it a 20-gm. weight. Set the fork into vibration with large amplitude. With what frequency, *i.e.* number of vibrations per second, is it vibrating? Are its vibrations free or forced?



Tuning Fork

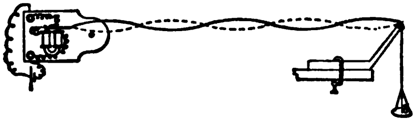


Fig. 33. — Electric Bell

Vibrations are *free* when the period is determined by the properties of the vibrating body. Thus the vibrations of a pendulum are free because its period is determined by its length. Vibrations are *forced* when the vibrating body has impressed upon it the period of some other vibrating body.

What is the frequency in the string? Is it free or forced?

Adjust the position of the support until the string vibrates in distinct loops. Make a diagram in which the nodes, loops, wave length, etc., are plainly marked. Why is a wave length two whole loops instead of one? Are the waves in this string stationary waves? Why?

Measure the length of a convenient number of half waves and thus compute the wave length. Calculate the speed of the wave motion from the frequency and the wave length. Why is $V = nl$? Arrange results.

Frequency of Fork...... Period...... $\left(\text{Period} = \frac{1}{\text{Frequency}}\right)$

Weight Attached	Number of Half Waves	Distance	Half Wave Length	Wave Length	Speed

Repeat the experiment attaching 80 gm. to the free end of the string. How does increase in tension affect the length of the wave? How does it affect the speed of the wave motion?

Repeat the experiment, using four-strand cotton and, at different times, weights of 20 and 80 gm. How does change in mass per unit length of the string affect the wave length? How does it affect the speed of the wave motion?

Application. — In a piano the strings are of different lengths stretched with different tensions. When the tension is the same, in which does the wave travel faster, the heavier or the lighter string? When the weight per unit length is the same, in which does the wave travel faster, the string with the high or the string with the low tension?

LENGTH OF A SOUND WAVE

Problem. — To find the length of a sound wave in air and in glass and to compare the speed of sound in glass with that in air.

Apparatus. — Kundt's tube (Fig. 34); meter stick; cotton or woolen cloth.

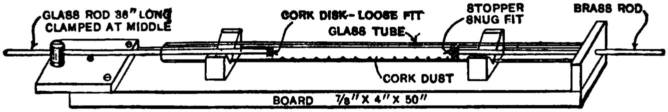


Fig. 34. — Kundt's Apparatus

Experiment. — Distribute cork dust along the inside of the large glass tube. Clamp the small rod at its middle point. The fixed point thus formed is a node. The ends of the rod are loops in the wave. What relation exists between the length of the rod and the length of the sound wave in it?

Set the small rod into vibration by drawing a dampened cloth lightly along it. Adjust the plunger in and out until the cork dust shows the greatest disturbance. What causes the disturbance in the cork dust? Are these stationary waves? What points are nodes? What points are loops? Is the distance from node to node or loop to loop a half or full wave length? Why? Measure the distance between two well-defined nodes as widely separated as possible. Calculate the length of a wave in air. Move the plunger and repeat the experiment two or three times. Record results in a tabular form. Is the number of vibrations per second (frequency) in the rod the same as in the air? Why are the wave lengths in glass and air different? If so, does the wave travel faster in glass than in air, and in what ratio?

Trial	Number of Half Waves in Air	Distance	Wave Length in Air	Length of Vibrating Rod	Wave Length in Glass	Ratio: $\frac{\text{W. L. in Glass}}{\text{W. L. in Air}}$
1						
2						
3						

Application.—If the speed of sound in this room is 345 m. per second, what is the speed of sound in the glass rod in the above experiment?

LAWS OF PITCH

Problem. — To observe in a vibrating string the relation between:

(1) pitch and length of string with a given tension,

(2) pitch and tension in the string with a given length,

(3) pitch and weight per unit length of string with a given tension and length.

Apparatus. — Sonometer having two strings of the same size wire; another string of different size wire; weights; bridge.

Experiment. — (1) Tune the two strings of the same size to the same note by adjusting the tension. Set the bridge under the center of one string and sound both strings. What is the relation between the pitches of the two tones? Similarly place the bridge under the third and fourth points of the string and answer the same questions as before. In general what relation exists between pitch and length?

(2) Tune the two strings as before to the same pitch. The stretching forces will be almost, if not quite, equal. Increase the tension in one string four times and compare the pitches. What relation exists between pitch and tension?

(3) Stretch two strings of unequal weight per unit length by

the same tensions. Which string gives the lower pitch? Is it true that in strings the pitch is inversely as the square root of the linear density? Did this experiment prove this result or would more careful experiments be necessary?

State these laws concisely.

Application. — 1. State two ways in which all the notes of the scale may be successively produced upon a single stretched string.

2. Why are strings of different lengths and densities used in building a piano?

3. How is a piano tuned? a violin?

4. Why are not all the strings of a violin of the same size?

THE PITCH OF A TUNING FORK

Problem. — To find the pitch (frequency) of a tuning fork.

Apparatus. — A sonometer; movable bridge; tuning fork of known pitch; tuning fork whose pitch is to be found; meter stick.

Experiment. — Tune both strings of the sonometer to the pitch of the known fork. Keeping the tension the same, move the bridge until one of the strings is in unison with the other fork. What is the relation between the frequencies of the two strings of different lengths? What is the relation between the frequencies of the two forks?

Calculate the frequency of the fork of unknown pitch.

Application. — Devise a method of standardizing the pitch of a fork for A. If it is originally too low in pitch how can its pitch be raised? If too high, how can its pitch be lowered?

FUNDAMENTAL AND OVERTONES

Problem. — To observe the manner in which a string vibrates when giving out a musical note.

Apparatus. — Sonometer; violin bow; rosin.

Experiment. — Tighten one string of the sonometer until it gives a good clear tone. Pluck it by the center. In what fraction of a whole wave length does the string vibrate? This tone is the *fundamental* of the string — *the tone of lowest pitch that the string can give out.*

Bow the string near one end until a good clear tone is produced. Is it the fundamental? Now touch the string lightly but quickly at its middle point. Is the note heard the *octave* of the fundamental? The octave gives just twice as many vibrations per second as the fundamental. Is then the ratio of their frequencies 2:1? The octave is the *first overtone.* Was it produced at the same time as the fundamental?

Touch the vibrating string at one third its length. The tone now heard is called the *fifth* above the fundamental. Its ratio to the fundamental is 3:1. It is the *second overtone.* In the same manner touch the vibrating string at its one fourth and one fifth points. What ratios represent their relation to the fundamental?

Are these overtones sounding at the same time as the fundamental? State concisely what is meant by the overtones of a given tone.

Application. — Account for the richness of tone from a 'cello or violin. Why do not all performers obtain the same quality of tone?

INTERFERENCE AND BEATS

Problem. — To explain the phenomenon of beats.

Apparatus. — Two forks of nearly the same pitch; soft wax; soft mallet or piano hammer.

Experiment. — Set the two forks in vibration. Attach some small pieces of soft wax to the fork of higher pitch until the forks are in unison. How can you tell when they are nearly of the same pitch? These pulsations of sound are called *beats.*

Load further one of the forks; *i.e.* attach small pieces of wax to both prongs. What effect does this have upon the frequency of the fork? Does it lengthen or shorten the wave length for that fork? What effect does it have on the number of vibrations per second (frequency)?

When the forks are in unison, the vibrations come to the ear so that we hear a single tone. When one fork has been loaded, the sound from the fork which has the lesser frequency falls behind that from the other fork until the waves sent out by the two forks are in opposite phase, *i.e.* trough to crest, or condensation to rarefaction. What is the effect upon the loudness of the sound? The wave sent out by the lower fork then falls farther behind until the forks are again vibrating in the same phase —

crest to crest, condensation to condensation. What effect upon the loudness of the sound?

Describe concisely how this experiment accounts for the beats.

Application. — 1. Why can the difference in frequency be told by the number of beats per second?

2. Two forks are sounded together and 18 beats are counted in 3 min. How far apart in pitch are the forks? If one fork has a frequency of 432, what may be the frequency of the other? Is it higher or lower?

3. How can you tell when a pair of strings on a mandolin are approaching unison?

RESONANCE

Problem. — To observe the phenomena of resonance and to explain why an air column of definite length vibrates sympathetically with a tuning fork.

Apparatus. — A heavy ball hanging from a support; a glass tube about 1 in. in diameter and about 30 cm. long; a bottle; siphon and rubber tube (Fig. 35); a tuning fork whose vibration number is known; a padded mallet.

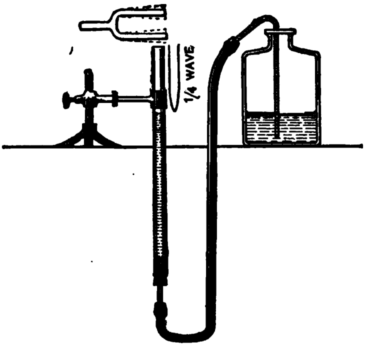


FIG. 35. — Tube with Water Piston

Experiment. — (*a*) Suspend the ball from any support. Tap it periodically with a pencil in such a way that its amplitude of vibration increases. What relation has the interval between taps to the period of the ball? Tap the ball at irregular intervals. Does the amplitude of vibration increase as before? Why not? Does a vibrating body take up vibrations of the same period as its own? When a body does take up vibrations of its own period, it is said to *vibrate sympathetically*. The phenomenon is called *resonance*. To be in resonance two vibrating bodies must have the same or almost the same period.

Experiment. — (*b*) Support the glass tube so that the length of the air column may be varied by a water piston (Fig. 35). Set the fork in strong vibration and hold it horizontally over the air column. Change the air column until the resonance between the fork and air column is strongest. Measure the length of the air column and to it add ¼ the diameter of the tube. (A portion of the air outside the tube vibrates as if it were a part of the tube. The correction is about ¼ the diameter of the tube.)

Find the temperature near the apparatus. Calculate the velocity of sound in air for this temperature. Knowing the vibration number of the fork, calculate the length of the wave it sends out. Is the corrected length of the air column about ¼ the wave length? Explain.

Application. — **Explain how an organ pipe emits its characteristic note.**

THE MERCURY THERMOMETER

Problem. — To locate on a mercury thermometer the freezing and boiling points of water.

Apparatus. — A mercury thermometer graduated from about — 10° C. to about 110° C.; a cup of clean cracked ice; a boiler (Fig. 36) with burner and tubing.

Experiment. — (*a*) *The freezing point.* The temperature of a mixture of clean ice and water is at the freezing point of water. Almost fill a cup with a mixture of clean cracked ice and water. Insert the thermometer bulb in this mixture, allowing the top of the mercury column to be just in sight. After the reading of the mercury becomes stationary, record this reading as the melting point of water. Does your thermometer record the freezing point correctly? If not, is its correction + or —? What correction must be added to or subtracted from the readings of this thermometer near the freezing point to obtain the correct temperature? What are the readings of the freezing point of water on centigrade and Fahrenheit thermometers respectively?

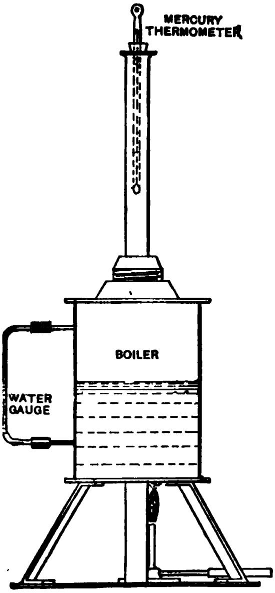


FIG. 36. — Boiler

Experiment. — (*b*) *The boiling point.* The temperature of the steam in contact with boiling water is taken as the boiling point of water. Pass the thermometer through the cork of the boiler. Open the upper vent and allow steam to circulate freely around the bulb of the thermometer. Keep the stem as low in the steam as possible without hiding the top of the mercury column. When the mercury reading becomes stationary, record the reading as the boiling point at barometric pressure. Why? To find the boiling point at 760 mm. pressure add to or subtract from 100° C. 0.037° for each mm. the barometer is above or below 760 mm. Does your thermometer indicate the boiling point correctly? If not, what correction must be applied to its readings near the boiling point of water? What are the readings of the boiling point of water on centigrade and Fahrenheit thermometers respectively?

Application. — 1. Find the correct temperature when a thermometer whose correction is + 2° reads − 5° C.

2. A centigrade thermometer reads 20°. What would a Fahrenheit thermometer read?

3. On a day when the thermometer reads − 2° F., what is the reading on a centigrade thermometer?

LINEAR EXPANSION

Problem. — To find the coefficient of linear expansion of brass.

Apparatus. — A boiler; rubber tubing; an expansion apparatus (Fig. 37); meter stick; thermometer; a metal tube or rod.

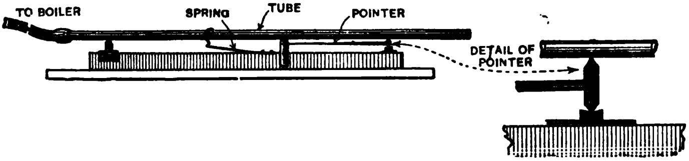


FIG. 37. — Linear Expansion Apparatus

Experiment. — The coefficient of linear expansion of a substance is defined as the change of length per unit length per degree of temperature. From this definition, evidently, the following quantities must be measured — the original length and temperature of the tube, its final temperature, and its change of length.

Measure the length of that part of the tube or rod whose change of length is to be measured. Set the tube in its supports so that any change of length of the rod will change the position of the pointer. Measure the temperature. If a tube is used, insert the thermometer in one end. Pass steam through the apparatus. How closely will the temperature of the apparatus be that of boiling water? After the steam has passed for a minute or two, record the new position of the pointer. Measure the length of each lever arm of the pointer, taking particular care to measure the length of the short arm accurately. Calculate from the movement of the long end of the lever how far the short end has moved. What is the relation between the change in length of the rod and the distance the short arm has moved? Calculate the coefficient of expansion of the metal.

Application. — Examine a table of coefficients of expansion and then explain why it is necessary to use platinum instead of copper wire in fusing in the terminals of electric light bulbs.

Why not use copper rivets in making a steam boiler?

Why use a compensated clock pendulum? Would a pendulum bar of invar do as well?

MELTING POINT OF A SOLID

Problem. — To observe the temperature at which paraffin melts.

Apparatus. — A piece of glass tubing with one end drawn down to capillary size, paraffin, thermometer, beaker, burner, support (Fig. 38).

Experiment. — Draw a small thread of melted paraffin into the narrow end of the capillary tube and seal the tube. Tie the tube to the thermometer so that the bulb of the thermometer is opposite the paraffin. Support the thermometer in the water. Heat the water gradually.

Note the temperature at which the paraffin at the very bottom of the tube begins to melt, *i.e.* begins to become

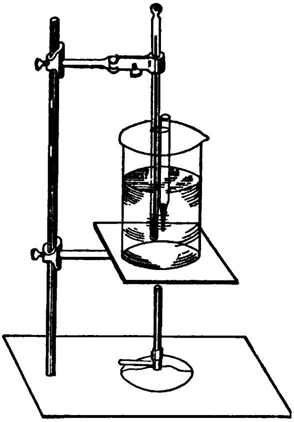


Fig. 38. — Melting Point

transparent. Stop heating. Cool the water slowly, possibly by the very cautious addition of cold water. Observe the temperature at which the paraffin again becomes opaque. Repeat these two operations at least two or three times and take their average as the melting point of paraffin.

As the temperature rises, which is at a higher temperature, the paraffin or the thermometer bulb? Explain. As the temperature falls, which is hotter, thermometer or paraffin? Explain why the above readings are averaged.

Do all substances melt at the same temperature? (See any table of melting points.)

Application. — Could Wood's alloy (melting point about 65° C.) be used to solder holes in an ordinary teakettle? Why?

What is the purpose of the soft plug in a steam boiler?

Can gold be melted in an iron pot? What are the respective melting points of iron and gold? Why can melted iron be carried in iron pots lined with fire clay?

BOILING TEMPERATURE OF A SOLUTION

Problem. — To observe the effect of the presence of common salt on the boiling temperature of a solution.

Apparatus. — A 500-cc. flask; stand with two rings; gauze; burner; thermometer; salt.

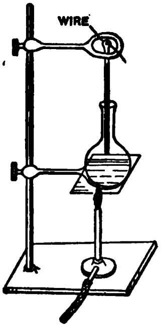


FIG. 39. — Boiling Temperature

Experiment. — Arrange the apparatus as shown in Fig. 39. The thermometer is suspended from the upper ring so that its bulb is above the water. Put about 200 cc. of water in the flask and bring it to a boil. Is the temperature of the vapor above the boiling liquid the same as that of the liquid itself? Find out by putting the bulb of the thermometer down into the liquid.

Now, through a cone of paper, add a small spoonful of salt to the liquid. Be sure that no salt or salt solution gets on the thermometer. Wash it off, if necessary. Boil again, testing the temperature of the vapor and the solution as before. What effect has the presence of a dissolved solid on the boiling temperature of the solution?

Add more salt and repeat observations as before. How does the amount of dissolved substance influence the elevation of the boiling point? Do all dissolved solids act in the same way as salt? Does any salt pass off with the steam?

How does a dissolved substance affect the freezing point of a solution?

Application. — Describe the process of distilling water and explain in what respects distilled water is purer than natural water.

How is a low temperature in refrigerator pipes maintained without freezing the liquid that the pipes contain?

Why do automobile storage batteries not freeze?

What is the anti-freezing mixture in an auto radiator and how does it work?

DEW POINT TEMPERATURE

Problem. — To observe the dew point temperature under various atmospheric conditions.

Apparatus. — A brightly polished can called a calorimeter; thermometer; ice; salt; burner; and cup for heating water.

Experiment. — *The dew point is that temperature at which the moisture in the air begins to condense.* Fill the calorimeter one quarter full of water, and stirring continually cool the water by adding *slowly* small bits of ice or ice and salt until a cloud of moisture forms on the outside of the calorimeter. Take the temperature at the instant the cloud appears. Where does this moisture come from and why does it condense?

Slowly warm the calorimeter by adding hot water *cautiously.* Stir continually. Take the temperature at the moment the cloud disappears. Average these two readings as the dew point. Why take the average?

Repeat the above operations and observations.

Repeat the experiment in another room or out of doors. Why does the observed dew point differ from one room to another?

Application. — Why does a cloud of "steam" come from the exhaust pipe of a locomotive? (Is steam visible? Is water vapor visible?)

How is rain caused? Is the dew point lower, on the average, in summer or in winter?

METHOD OF MIXTURES

Problem. — To observe the manner in which heat exchange takes place between bodies placed in thermal connection.

Apparatus. — Calorimeter; thermometer; supply of hot and cold water; balance; weights.

Experiment. — Weigh the calorimeter.

Weight ———— gm.

Into it weigh about 200 gm. of hot water at about 60° C.

Weight of calorimeter and water ———— gm.

In another dish take about 200 cc. of cold water. Take its temperature. Take the temperature of the hot water.

Temperature hot ————; cold ————.

Pour the cold water into the hot. Stir thoroughly and take the temperature of the mixture.

Temperature of mixture ————.

Weigh the calorimeter and contents.

Weight of calorimeter and mixture ———— gm.

Calculate the weight of cold water added.

Weight of cold water ———— gm.

Definitions. — A **calorie** is the amount of heat required to raise the temperature of one gram of water one degree centigrade. Heat in calories is therefore calculated by multiplying mass of water in grams by change of temperature.

The *water equivalent* of a body is that weight of water which has the same capacity for heat as the body. It is found by multiplying the weight of the body by its specific heat.

Compute the water equivalent of your calorimeter. (It is made of brass, and the specific heat of brass is about 0.1.)

Water equivalent = weight calorimeter × 0.1 = ———— gm.

Since the hot water is in the calorimeter, both keep the same temperature. The water equivalent of the calorimeter may be added to the weight of hot water and the sum treated as the weight of the cooling body. Calculate the heat given out by the cooling body.

Heat given out = weight of cooling body × its change of temperature = ———— calories.

Calculate the heat absorbed by the bodies warmed.

Heat absorbed = weight of cold water × its change of temperature = ———— calories.

Is the heat taken in by the bodies warmed equal to the heat given out by the bodies cooled? Why should the quantities of heat be equal? Why are they different?

The statement of equality between the heat lost and the heat gained bv bodies in thermal connection is called the *heat equation.*

Arrange the above results in a neat tabular form.

Repeat the experiment once or twice.

If heat is a form of energy, do the above results agree with the principle of the conservation of energy?

Application. — What becomes of the heat produced when coal is burned under a boiler?

SPECIFIC HEAT

Problem. — To find the specific heat of copper.

Apparatus. — A boiler; cup in which to heat copper (the dipper, Fig. 40); thermometer; calorimeter and cover; copper punchings; balance and weights.

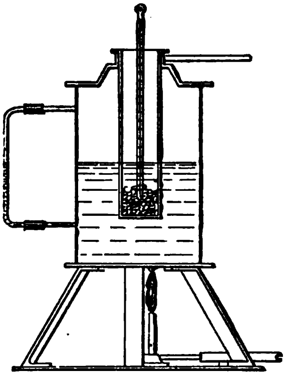


FIG. 40. — Boiler and Dipper

Experiment. Dry and weigh the calorimeter. Weigh out about 300 gm. of copper; put it in the dipper. Insert the dipper in the boiler and heat as hot as possible. (Usually the copper may be heated to about 96° or 98° C.) Take the temperature by carefully pushing the thermometer bulb down among the punchings. Meanwhile weigh about 100 gm. of cool water into the calorimeter. Take its temperature and immediately pour the copper into the water. Cover and stir, observing the temperature at which the mercury becomes almost stationary or else only drops very slowly.

Calculate the heat taken in by the water in warming. The initial temperature, the final temperature, and the weight of the water must be known. Have you made the necessary observations? Calculate the heat gained or lost by the calorimeter. Its water equivalent is about $\frac{1}{10}$ of its weight.

The water equivalent of the copper taken is the product of its weight by its specific heat. The latter is the number we wish to find. Represent it by x. Calculate the heat lost by the copper in cooling. Its initial temperature, final temperature, and the weight of the copper must be known. Have you made the necessary observations?

Apply the principle of the conservation of energy to the formation of a heat equation. Is the heat lost by the copper equal to the heat gained by the calorimeter and water?

The heat equation is:

Heat lost by the copper in cooling to the temperature of the mixture = heat gained by the water + heat gained by the calorimeter.

(No allowances are made for heat lost or gained by radiation and convection.)

The resulting equation has one unknown quantity; namely, the specific heat of copper. Calculate it.

Arrange results in a tabular form thus:

Weight of copper taken ———
Temperature of copper ———
Weight of calorimeter ———
Water equivalent of calorimeter ———
Weight of water taken ———
Temperature of water ———
Temperature of mixture ———
Heat lost by copper ———
Heat gained by water ———
Heat gained by calorimeter ———
Heat equation
Specific heat of copper ———

Application. — Do all metals have the same specific heat? Is this a characteristic property by which one metal may be distinguished from another?

Why does a large body of water serve to equalize the temperature of the adjacent country?

HEAT OF VAPORIZATION

Problem. — To find how much heat is liberated by one gram of steam on condensing into water (heat of vaporization of steam).

Apparatus. — Boiler; water trap (Fig. 41); calorimeter and cover; thermometer; balance and weights.

Experiment. — Weigh the calorimeter. Weigh into it about 300 gm. of cold water. Connect bend to water trap and to boiler. Be sure that connections are all tight. When steam is issuing freely from the end of the glass bend, take temperature of the cold water and conduct steam into the water. Stir continually. (If the experiment is going properly, the sharp crackle of the steam bubbles condensing in the water will be clearly audible.) When the temperature has risen to 35° or 40° C., stop the admission of steam by quickly removing the end of the glass bend from the water. Take the temperature exactly. Weigh. How can you calculate the weight of steam that has been condensed?

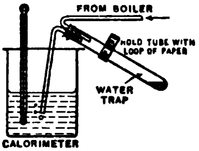


Fig. 41. — Vaporization

Calculate the total heat received by (given to) the water and calorimeter. Calculate the heat given out by the condensed steam in cooling to the temperature of the mixture. Is this equal to the total heat above? Where did the heat unaccounted for come from? If this was given out in the condensation of a known weight of steam, how much heat was given out per gram of steam? This is called the *heat of vaporization of water.*

Arrange the above results in a tabular form and write the heat equation for the experiment as follows:

Heat given out by the steam in condensing (*i.e.* weight of steam × heat of vaporization) + heat given out by the condensed steam in cooling to the temperature of the mixture = heat absorbed by the original water + heat absorbed by the calorimeter.

The unknown number in this equation is the heat of vaporization.

Application. — One cubic centimeter of water at 100° C. expands into about 1700 cc. of steam at the same temperature and at atmospheric pressure. If heat is work, explain why the heat of vaporization of water is such a large number.

Why is steam such an excellent vehicle for energy? For example, the work done by steam at a pressure of 250 lb. per square inch expanding in

two cylinders 18 in. in diameter with a 24-in. stroke drives a freight train weighing 2500 T. 30 mi. per hour.

TABULAR FORM

Weight of calorimeter ———
Weight of calorimeter and water ———
Weight of water ———
Temperature of water ———
Temperature of mixture ———
Weight of calorimeter and mixture ———
Weight of steam condensed ———
Heat absorbed by calorimeter ———
Heat absorbed by water taken ———
Heat given out by condensed steam ———
Heat given out by steam in condensing ———
Heat equation
Heat of vaporization of water ———

HEAT OF FUSION

Problem. — To find how much heat is required to melt one gram of ice (heat of fusion of ice).

Apparatus. — Ice cracked fine; warm water; calorimeter and cover; thermometer; balance and weights.

Experiment. — Weigh the calorimeter and into it put about 250 gm. of water at say 50° to 60° C. Weigh again. Record the temperature of the water in the calorimeter. Is the calorimeter at the same temperature? Dry some pieces of ice. Do not be too particular. Add pieces of ice to the water, stirring constantly until the temperature has dropped to 10° or 15° below the temperature of the room. Why have the ice dry when added? Observe the temperature as the last bit of ice melts. Weigh again. How may the weight of ice added be calculated?

Calculate the heat required to cool the water through the observed range of temperature. Calculate the heat required to cool the calorimeter. Through what range of temperature was the melted ice warmed? Calculate the heat thus absorbed.

What has become of the balance of the heat given up by the water and the calorimeter? This quantity of heat may be thus expressed: Weight of ice × heat of fusion = ———. Why is this heat sometimes called "latent heat"?

The heat equation for this experiment is:

Heat absorbed by ice in melting + heat absorbed by melted ice in coming to the temperature of the mixture = heat given out by water in cooling to the temperature of the mixture + heat given out by the calorimeter.

Calculate the heat per gram required to melt ice. It is the unknown number in the heat equation. What is the correct value for the heat of fusion of ice? Is the heat of fusion the same for all substances?

Arrange results in a tabular form similar to that for heat of vaporization.

Application. — When large quantities of ice have formed in a lake or river, why does the ice melt so slowly when a thaw comes?

In a mixture of ice and water well stirred, why does the whole remain at the freezing point until all is melted?

ELECTROSTATICS

Problem. — To charge an electroscope and to test the character of an electric charge.

Apparatus. — Electroscope; vulcanite rod; glass rod; pieces of flannel and silk; proof plane (penny fastened to a glass rod by a bit of wax).

Note. — The success of this experiment depends largely upon having the electroscope, rods, and cloths dry and warm. Mark one end of each rod and then handle by the marked end only.

Experiment. — Rub the vulcanite rod with flannel and observe its effect upon some small bits of paper. *A body that has this property of attracting other light bodies is said to be electrified, or charged.* At first the bits of paper are attracted, but after coming in contact with the charged body, they are projected away from it. Do like charges of electricity attract or repel?

Rub the vulcanite rod again. Touch it with the proof plane and then touch the latter to the knob of the electroscope. Why do the leaves of the electroscope diverge? Is the charge on the leaves of the same kind as that on the vulcanite rod? The electroscope is now *charged by conduction.*

The charge on vulcanite rubbed with flannel is *negative.* The charge produced by conduction is always the same as that of the body from which the charge was derived.

Discharge the electroscope by touching the knob with the finger. Repeat these experiments with a glass rod rubbed with silk. The charge on glass rubbed with silk is *positive.*

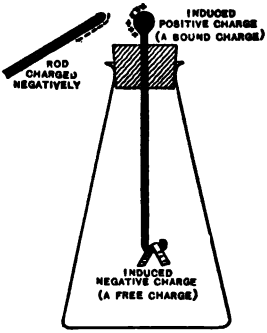

INDUCED POSITIVE CHARGE (A BOUND CHARGE)
ROD CHARGED NEGATIVELY
INDUCED NEGATIVE CHARGE (A FREE CHARGE)

FIG. 42. — When a negatively charged body is brought near an electroscope

Discharge the electroscope. Charge it negatively by conduction and then transfer a positive charge to it. Why do the leaves collapse? Do unlike charges, when equal in quantity, neutralize one another? Do unlike charges of electricity attract or repel?

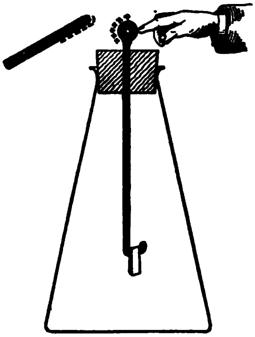


FIG. 43. — The finger conducts away the free charge on the leaves

Discharge the electroscope. Electrify the vulcanite rod and hold it several inches from the knob of the electroscope (Fig. 42). Are the leaves charged? Keep the rod at a distance but touch the knob momentarily with the hand (Fig. 43). Why do the leaves collapse? What has become of the charge that was on the leaves? Remove the charged rod (Fig. 44). Why do the leaves separate? This charge was *induced* by the charge on the vulcanite rod.

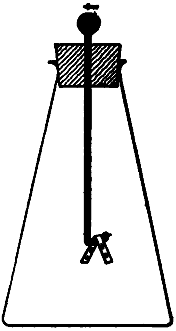


FIG. 44. — When the rod is also removed, the bound (+) charge is distributed on both knob and leaves

To find out whether the induced charge is like or unlike the inducing charge, proceed as follows: Charge the vulcanite rod (a negative charge) and touch it with the proof plane. Touch the latter to the knob of the electroscope. Why do the leaves collapse? Was the induced charge positive or negative?

The permanent charge produced by induction is always opposite to the inducing charge.

If the electroscope is positively charged and the leaves diverge farther when a charge of unknown kind is brought up, is this charge +

or —? Describe concisely how to tell the sign of the charge on any charged body.

Application. — 1. Charge the electroscope negatively by induction. (Start by electrifying a glass rod.) Draw three diagrams illustrating the three stages of the process. (Compare Figs. 42, 43, and 44.)

2. During a thunderstorm, if the clouds are charged positively, how is the earth charged? Draw a diagram to illustrate.

3. How does a moving belt become electrified?

MAGNETIC FIELD

Problem. — To observe the characteristics of a magnetic field.

Apparatus. — Two bar magnets; a grooved board (Fig. 45); a pane of glass; a small compass; a sifter and iron filings.

Experiment. — Suspend one of the bar magnets in a stirrup of paper so that it swings freely. Mark its north-seeking end. This is called the *north* pole of the magnet. Repeat with the other magnet. Present the north pole of the first magnet to that of the one suspended. Do they attract or repel? Repeat with the south pole. What is the law of attraction for magnetic poles?

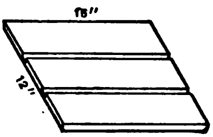


FIG. 45. — Grooved Board

Lay one of the magnets on the grooved board with its north pole toward geographical north. Lay the pane of glass over the magnet. Sift filings lightly over the glass and rap sharply so that they may assume a definite pattern. Make a sketch showing the arrangement of the filings. Clean them off and place the small compass at various points on the glass and make arrows on your diagram showing the *sense* in which a north pole points. *A north pole points along a line of force.* Do lines of force run into or out of a north pole? A south pole? Are lines of force closed curves? Are they confined to the plane of the glass? The space in which the lines of force of a magnet lie is called its *magnetic field.*

Does the field of one magnet interfere with or modify the field of another? Try it with your two magnets. Make a sketch.

Application. — How large is the earth's field? How does it affect the field of any other magnet? Where is the north magnetic pole of the earth? Is it north-seeking or south-seeking?

Note. — The form of these fields may be permanently preserved as follows: Coat a clean pane of glass lightly with very thin white shellac. Dry thoroughly. Lay on the magnet board. Sprinkle filings as before. Carefully lift off the pane of glass and heat cautiously until the shellac melts. The filings stick to the shellac and the map of the magnetic field may be preserved for reference.

MAGNETS

Problem. — To observe the various methods of making magnets and the properties of magnetic and non-magnetic substances.

Apparatus. — Two bar magnets about 6 in. long; iron filings; small nails; watch spring; small compass; narrow strip of tin; pieces of brass, lead, etc.

Experiment. — Draw a piece of watch spring over the north pole of a magnet. Test its polarity with the compass. Magnetism has been induced in the watch spring by bringing it into the field of the magnet. Is the end that left the magnet last a north or a south pole? Does a pole induce a like or an unlike pole? State concisely one method of making a magnet.

Break up the magnetized piece of watch spring into small pieces. Is each piece a magnet? Is it probable that the ultimate particles of the steel — namely its molecules — are magnets? If so, how could you explain the above method of making a magnet?

Present a soft iron nail to the compass. Is it magnetized? Does it attract both poles of the magnet? A body which attracts both poles of a magnet but is not itself magnetized possesses *magnetic quality* and is a *magnetic substance.* Are lead, copper, gold, silver, etc., magnetic or non-magnetic? Name the common magnetic substances.

Lay an unmagnetized piece of hard steel in the field of a strong magnet and rap it sharply. Remove it and test its magnetism by the compass. Is it a magnet or simply a magnetic substance? How did it become a magnet? Explain by the molecular theory of magnetism. What does the *induction* of magnetism mean? A magnetic substance likewise acts as a magnet while in the magnetic field. What effect does a magnetic substance have upon the lines of force?

Take a strip of unmagnetized tin about ½ in. by 6 in. Hold it by the two ends in a north and south direction and twist it slightly a few times. Test it for magnetism. Explain. Demagnetize it by twisting it while held in an east and west position.

Application. — There is a strong magnetic field around the field magnets of a dynamo. How could a piece of steel be magnetized by means of it?

Why are the cores of an electromagnet always made of soft iron?

THE VOLTAIC CELL

Problem. — To produce an electric current by a voltaic cell and to describe the action of the cell.

Apparatus. — A small jar of dilute sulphuric acid; wire; a small compass or galvanoscope; strips of zinc, copper, lead, etc.; connectors; amalgamating solution; water battery.

Experiment. — (*a*) Dip a single strip of copper into the acid. Is there any evidence of chemical action? Dip two strips of copper into the solution. Do not allow them to touch. Connect them externally by a wire. Is there any indication of current even when tested by a delicate galvanometer?

(*b*) Now try a single zinc strip, observing the chemical action. What gas is given off? This is called *local action.* Try two zinc strips in the same way as the copper strips.

The liquid is called the *electrolyte.* The strips are called *electrodes.* When like electrodes are dipped into an electrolyte, does a current flow through the external circuit?

(*c*) Now try one zinc strip and one copper strip, connecting them externally by a wire but keeping them carefully separated in the electrolyte. This series of conductors and electrolyte form a *circuit.* Does a current flow when the electrodes are of different metals? In which sense does this current flow, copper to zinc or zinc to copper? If current flows from + to –, which electrode is + and which –? Such a pair of electrodes are said to set up a *difference of electrical pressure.* Is the electrical pressure the same between any two metals as between copper and zinc? What are the necessary parts of a voltaic cell? Upon what does the electrical pressure depend?

(*d*) While the circuit is closed, do any bubbles of hydrogen escape at the surface of the copper? How do they get from the zinc plate where the chemical action takes place to the copper plate? Is it correct to say that hydrogen travels with the current? As the circuit remains closed, what effect does the accumulation of hydrogen, invisible and also in the form of bubbles, on the copper strip have on the strength of the current? This action is called *polarization.*

(*e*) Coat a zinc plate with mercury. The zinc is now *amalgamated.* Place it alone in the acid. Is there as much local action as with an unamalgamated zinc? How then may local action be prevented? As before, make a circuit with copper, amalgamated zinc, electrolyte, and external conductor. Where do the bubbles of hydrogen now appear? Is hydrogen carried with the current?

(*f*) Set up a battery of 50 or more cells in series (water battery). Connect the copper terminals to a glass rod and touch the terminal to the plate of an electroscope with condenser top. Touch the zinc terminal similarly to the other plate. Remove the connections. Then remove the upper plate of the condenser. Is the electroscope charged? Were these charges set up along with the chemical action in the cell? If so, what kind of charges did the hydrogen carry to the copper plate?

Why do we say that a current flows from the copper to the zinc? In what does a current probably consist?

Application. — Give some reasons for using zinc, carbon, and sal ammoniac in a dry cell; for using lead plates and sulphuric acid in a storage battery.

TWO-FLUID VOLTAIC CELLS (Review Experiment)

Problem. — To study the action of a Daniell and of a gravity cell.

Apparatus. — A gravity cell which has stood on short circuit until it has cleared up; a Daniell cell; voltmeter; No. 18 copper wire.

Note. — The *gravity cell* consists of a copper plate in copper sulphate solution and a zinc plate in zinc sulphate solution. Put the copper element in the bottom of the jar and spread copper sulphate crystals around it. Pour in water so as to stir up the solution as little as possible. Hang the zinc element over the edge of the jar and cover it with clear water or some very dilute sulphuric acid. Short circuit the battery until it clears up. The liquids then keep apart by gravity as long as the current flows.

The *Daniell cell* is chemically the same as the gravity cell. The solutions are kept apart by a porous jar. To set it up, put the zinc element into the porous cup and fill it within an inch of the top with very dilute sulphuric acid. Put quite an amount of copper sulphate crystals into the perforated cup and set both cups and the copper element into the large jar. Fill the latter with water within a half inch of the level of the liquid in the porous cup. Short circuit the battery until the current becomes constant.

Experiment. — Connect the Daniell cell to the voltmeter and record the reading. Do the same with the gravity cell. Short circuit each with a piece of No. 18 copper wire and let them stand. If a simple copper-zinc-sulphuric acid cell were treated in this manner, what effect upon the fall of electrical pressure between its terminals and upon the current strength would be observed?

After a time again insert the voltmeter and take reading. Does the electrical pressure remain constant? the current? Is there any evidence of polarization? Are any bubbles liberated?

Examine the copper plate. Where did the fresh deposit come from? Examine the zinc plate. Why does its surface appear pitted?

If the cell is allowed to stand on short circuit until it is exhausted, what is the color of the remaining solution? Is it zinc sulphate solution?

Describe the changes that take place in the elements and solutions as the current flows. What relation exists between the amount of current and the amounts of copper deposited and zinc dissolved?

Application. — 1. On telegraph circuits, where a steady current is desired, gravity cells are commonly used. Explain why.

2. In the laboratory the Daniell cell is one of the standard cells; *i.e.* it can be depended upon for a constant electromotive force. Explain.

INDUCED CURRENTS—PRINCIPLE OF THE DYNAMO

Problem. — To find out how to produce an electric current by induction.

Apparatus. — Two coils of wire, a primary with 20 turns of No. 18 wire and a secondary with about 200 turns of No. 30 copper wire; one or two strong dry cells; a sensitive galvanometer.

Experiment. — (*a*) Shunt the galvanometer (Fig. 46) with a piece of heavy copper wire. Now touch cautiously the terminals of one of the dry cells with the galvanometer and observe in which direction its indicator is deflected when a current flows through it from the right to the left-hand terminal. Let us call a deflection in this direction a *direct* current; in the opposite direction, an *inverse* current.

(*b*) Remove the shunt and connect the secondary coil in its place. Suddenly bring up the north pole of a magnet to one face of the secondary. This means an increase in the number of lines of force passing through the coil. Is a current produced? Is it direct or inverse? Is the sense of the current such as to make the face of the coil to which the north pole was presented a like or an unlike pole? Did the current produced aid or oppose the motion of the magnet?

Now suddenly remove the north pole from the face of the secondary. Answer the same questions as before.

(*c*) Connect the primary with a battery. Does it behave like a magnet? Repeat the above experiments, presenting one face and then the other of the primary to the secondary. Answer questions as before.

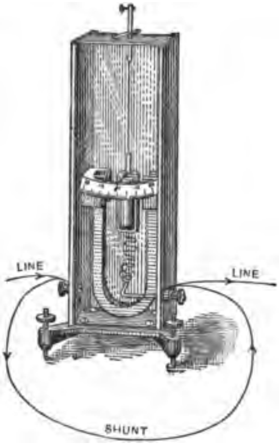


Fig. 46.—A Shunted Galvanometer

(*d*) Set the primary and secondary side by side, and make and break the primary circuit. Answer questions as before.

(*e*) Hold the primary with one face of the coil opposite the face of the secondary and rotate it quickly one quarter turn about a diameter. What current does the deflection indicate? Rotate a second quarter turn. In which sense does the current flow? Rotate a third quarter turn and then a fourth, answering the same question as before. How many times does the current change direction as the coil rotates once around?

What is a direct current? What is an alternating current?

Application.—Name and describe briefly the essential parts of a dynamo, and tell the function of each part.

What is the mechanical difference between a D.C. (direct current) and an A.C. (alternating current) generator?

ELECTROLYSIS

Problem.—To show that electrolytes are decomposed when a current flows through them.

Apparatus.—Source of current giving more than six volts; water; sulphuric acid; battery jar; solution of copper sulphate; copper plates; apparatus for the electrolysis of water; electric light carbon; iron plate.

Experiment.—(*a*) Put some dilute sulphuric acid into the electrolysis apparatus and connect the battery. What are the gases given off? Which one is given off at the *cathode* (point where the current leaves the electrolyte)? Which one at the *anode* (point where the current enters the apparatus)? Do you find again that hydrogen travels with the current? As long as the current remains constant, the liberation of gas takes place at a constant rate. Could such an apparatus be used as a device for measuring the rate at which current flows; *i.e.* the strength of the current? What observations would be necessary?

(*b*) Clean two copper plates with sandpaper or with nitric acid. Put copper sulphate into a jar or tumbler and insert the plates. Make one the anode and the other the cathode and allow the current to flow for some time. What change in the appearance of the two plates? The anode loses in weight, the cathode gains. Does copper travel with the current? Pure copper only is deposited on the cathode. How could this process be applied to the refining of copper?

(*c*) Replace the cathode plate by a stick of carbon and pass the current as before. What is deposited on the carbon? Repeat with a clean iron plate as cathode.

(*d*) Examine an electrotype and describe the process of making it.

(*e*) Dip wires connected with the two terminals of the battery into a solution of common salt in water. Is gas given off at both poles? What gas is given off at the cathode? From this experiment devise a method of determining in which sense a direct current is flowing.

Why will not a similar method apply for an alternating current?

Application.—How may the principles of electrolysis be applied to

(1) the measurement of current,
(2) electroplating,
(3) refining metals?

Why cannot an alternating current be used for electrolysis?

RELATION BETWEEN RESISTANCE AND FALL OF ELECTRICAL PRESSURE

Problem. — To observe the relation between resistance and fall of electrical pressure in a current-carrying conductor.

Apparatus. — Several meters each of Nos. 18 and 24 G. S. (German silver) wire and No. 24 copper wire; source of current; voltmeter, or galvanometer in series with such a resistance that it will serve as a voltmeter; a piece of fine iron or G. S. wire.

Experiment. — (*a*) For a moment only short circuit the battery with the piece of iron or G. S. wire. Why does the wire heat? What do we call the property of a wire which produces the heating effect observed?

(*b*) Connect, say, 6 m. of No. 18 G. S. wire, 6 m. of No. 24 G. S. wire, and 6 m. of No. 24 copper wire in series with the battery (Fig. 47). In which part of the circuit is the resistance the greatest: (1) through the copper wire, (2) through the larger G. S. wire, (3) through the smaller G. S. wire? (Consult a wire table.) In which part of the circuit is the heating effect the greatest?

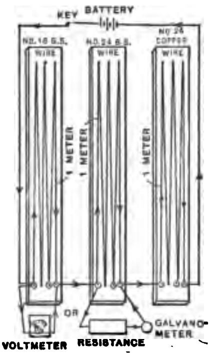


FIG. 47. — Resistance Boards

(*c*) Connect the voltmeter to the terminals of the smaller G. S. wire so as to measure the fall of electrical pressure across 6 m. of it (Fig. 47). Repeat across 4 m. and then across 2 m. What relation exists between the three falls of electrical pressure? What relation exists between the fall of electrical pressure and the resistance?

(*d*) Repeat with the larger G. S. wire, answering questions as before.

(*e*) Repeat with the copper wire, answering questions as before.

Application. — From your observations compare the resistance of Nos. 18 and 24 G. S. wire. Compare the resistance of No. 24 G. S. wire and No. 24 copper wire.

What effect has the size of wire on its resistance?

What effect has the material of the wire on its resistance?

What effect has the length of the wire on its resistance?

ELECTROMAGNETISM

Problem. — To investigate the magnetic properties of the region about a wire and about a helix when an electric current is flowing through them.

Apparatus. — A helix, single loop of wire, and a close coil of wire all mounted on a board (Fig. 48); straight wire; iron filings; sifter; small compass; pieces of iron; source of direct current.

Experiment. — Connect the straight piece of wire in circuit with the source of current. You will be told in which direction the current is flowing. Hold the wire above the compass needle and parallel to it. Grasp the wire with the right hand, the thumb extending along the wire in the sense in which the current is flowing. What is the relation between the fingers and the deflection of the north pole? Place the compass in various positions around the wire. Does the relation still hold? State the right-hand rule for finding the direction of a current. Why is the compass thus deflected? Is there a magnetic field about the wire? What is its shape and direction?

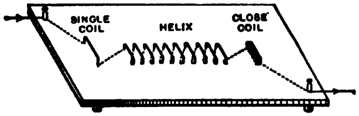


Fig. 48. — Coil Board

Connect the helix to the source of current. Sift iron filings on the board and tap gently. What shape do the filings take about the separate wires? About the helix as a whole? About the close coil of wire? Draw diagrams. What properties does a helix or coil of wire possess when a current is flowing through it? What effect upon these properties when a piece of iron is placed within the coil? Try it, sifting filings as before.

Application. — Describe an electromagnet. What is the purpose of the coil of wire? Of the soft iron core?

Describe a lifting magnet and explain its action.

Using a small compass, how may a circuit be tested without breaking the circuit, to find out whether a current is flowing? How tell the sense in which the current is flowing?

BELL CIRCUITS

Problem. — To set up a simple bell circuit and to draw diagrams for various other bell circuits.

Apparatus. — Electric bell; two dry batteries; wire; push button.

Experiment. — Connect the push button and bell in series with the batteries. Why does the bell ring when the button is pushed? Adjust the bell if necessary.

Explain in detail how the bell hammer automatically makes and breaks its own circuit. Draw a diagram and trace the current, indicating its direction by arrows.

Application. — 1. Draw a diagram showing how both front and back door bells may be rung from the same battery. Trace the current and indicate its direction by arrows.

2. Draw a diagram showing how two bells may be rung from one push button at the same time. Can they be connected in series? Trace and indicate current as before.

3. Draw a diagram showing how one bell may be rung from either of two push buttons.

TELEGRAPH CIRCUITS (Review Experiment)

Problem. — To observe the method of signaling by key and sounder, or by key, relay, and sounder.

Apparatus. — Telegraph sounder (4 ohms resistance); two batteries; key; relay. (In this experiment dry cells are satisfactory. In practice gravity cells are most commonly used.)

Experiment. — Connect the batteries and sounder in series with the key (Fig. 49). Describe precisely what takes place in the sounder when the key is depressed and raised. How is this used in signaling? Does it differ in principle from the electric bell? Could Morse signals be given with an ordinary multiple stroke electric bell? Could they be given by a single stroke bell?

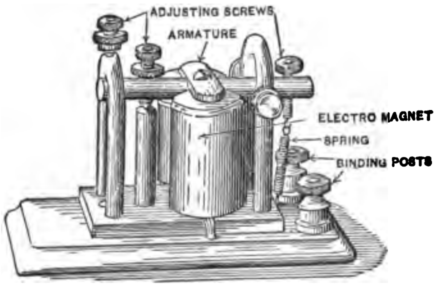


Fig. 49. — A Sounder

Connect a battery and key in series with the line terminals of the relay (Fig. 50). The magnet coils of a relay are in the main line. Describe exactly what happens in the relay when the key is depressed.

Insert a sounder and battery in the local circuit of the relay (Fig. 50). With the finger move the armature back and forth. Does the armature of the relay serve as a key to the sounder circuit? Now describe exactly what happens in the entire circuit when the key is depressed in the main line.

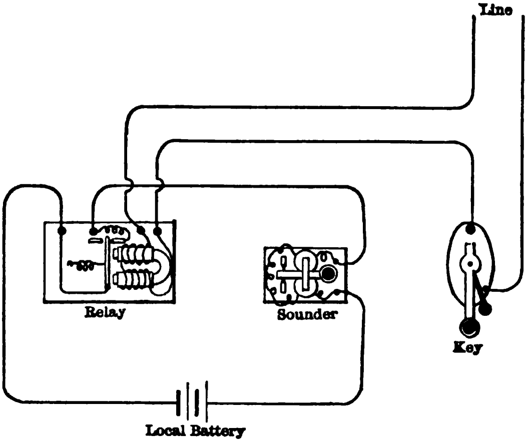


FIG. 50. — Key, Relay, and Local Circuit

Application. — Draw a diagram of a two-station telegraph line arranged so that signals may be sent or received at either end.

WHEATSTONE'S BRIDGE

Problem. — To measure resistance by Wheatstone's Bridge.

Apparatus. — A Wheatstone's Bridge of slide wire form; galvanometer; dry cell; commutator; key; a known resistance; an unknown resistance.

Experiment. — Connect the apparatus as shown in the diagram (Fig. 51). *C* is a movable contact. Close the key and then momentarily make contact at *C*. Observe the deflection of the galvanometer. Move the contact *C* and again observe the deflection. When the direction of deflection changes, explore the

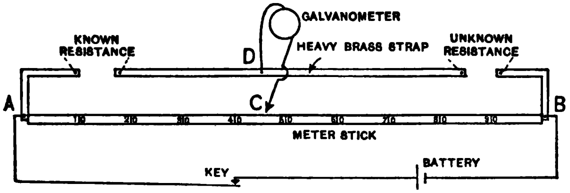


FIG. 51. — Wheatstone's Bridge

portion of wire between the positions of C, showing opposite deflections, until a point is found where no deflection of the galvanometer is observed. (If this position of C is near either end of the slide wire, change the known resistance until C is near the center of the slide wire, for no deflection in the galvanometer.) Why does no current flow through the galvanometer? Are the falls of electrical pressure from A to D and A to C the same? Similarly from D to B and C to B? Since the wire AB is uniform in cross section, are the resistances of AC and CB proportional to their lengths? The resistances from A to D and from D to B are proportional to the lengths AC and CB. Remember that fall of electrical pressure is proportional to resistance and that the fall of pressure from A to D is equal to the fall from A to C. Form a proportion. How many terms are known? Calculate the value of the unknown resistance.

Measure other unknown resistances.

Application. — Measure the resistance of two coils of wire. Then connect the same coils in parallel and measure their resistance again. Is their combined resistance correctly expressed thus, $\frac{1}{R} = \frac{1}{r_1} + \frac{1}{r_2}$? How then may the combined resistance of resistances in parallel be calculated?

THE PHOTOMETER (Review Experiment)

Problem. — To find the candle power of a source of light.

Apparatus. — A Bunsen photometer (Fig. 52); several standard candles; lamp.

Experiment. — Set up two candles, one at each end of the photometer bench, and move the screen until the grease spot disappears. What is now the intensity of illumination on the two sides of the screen? What is the relation between the distances of the candles from the screen?

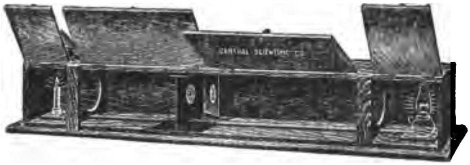

CENTRAL SCIENTIFIC CO.

FIG. 52. — Bunsen Photometer

Repeat, using two candles at one end and one at the other. What relation exists between the intensity of the light and the distance from the screen? State the *law of inverse squares.*

Place a lamp at one end of the photometer bench and the candle at the other and measure the candle power of the lamp.

Application. — How is the candle power of an incandescent lamp determined?

REFLECTION OF LIGHT

Problem. — (1) To observe the relation between the angles of incidence and reflection and (2) to locate the position of an image as formed by a plane mirror.

Apparatus. — A strip of thin looking-glass about ½ in. wide; blocks of wood or similar supports to which the mirrors may be attached by rubber bands; pins; protractor; ruler.

Experiment. — (1) Across the middle of a flat sheet of paper draw a fine thin line, *LL'* (Fig. 53). Set the reflecting surface carefully on this line. Set two pins in front of the mirror in any line, making an angle of about 45° with it. Mark them *I* and *II*, as in the diagram. In line with the images of these pins set two other pins *III* and *IV*. Must the pins be erect? Sight along the plane of the paper so as to use, as far as possible, the bottoms of the pins only.

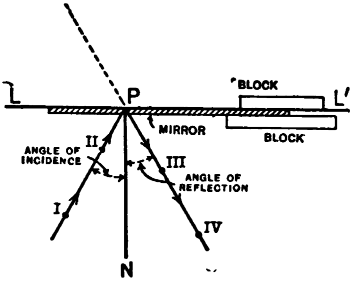


Fig. 53. — Reflection at a Plane Surface

Remove the mirror and support and draw lines connecting *I–II* and *III–IV*. Produce them until they meet. Should they meet at the reflecting surface? Why?

At their point of intersection *P* erect a perpendicular *PN* to *LL'*. This is called the *normal*. The angle *IPN* between the incident ray and the normal is the *angle of incidence*. The angle between the reflected ray and the normal is called the *angle of reflection*. Measure these angles and compare them.

Repeat three or four times with different angles of incidence. Enter results in tabular form. What relation exists between angles of incidence and reflection?

Experiment. — (2) On another sheet of paper draw a fine thin line *LL'* and set the reflecting surface exactly upon it as before. In front of the mirror and about 5 cm. from it, set up a pin as at

A in Fig. 54. Viewing the image of *A* in the mirror, set up a second pin at *B*, so as to coincide exactly with the image of *A*. When this is the case, the top of the pin *B*, as seen above the mirror, will appear to be a prolongation of the image of *A*, as seen in the mirror, and this will be true from whatever position they are viewed.

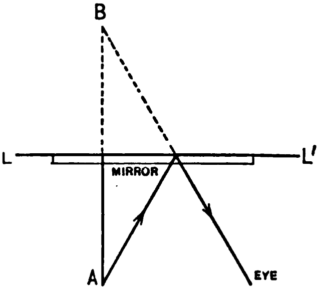


FIG. 54. — Position of the Image

Accordingly, set *B* in line with the image of *A*; then move the eye to one side. If the image of *A* and *B* appear to separate, move *B* until they coincide from whatever position they are viewed. *The one which moves in the same direction as the eye is farthest from the mirror.* This is called the *method of parallax.*

Remove the mirror. Draw the line *AB*. Should it be at right angles to the mirror? Why? Measure the distances of *B* and *A* from the reflecting surfaces. Should they be equal? Why?

Summarize the laws of plane reflection.

Application. — Draw a diagram showing the appearance in a plane mirror of the image of the protractor as it lies in front of the mirror. Are its parts arranged in reverse order in the image? Why?

What effect does a plane mirror have on the appearance of an image?

REFRACTION

Problem. — (1) To observe the path of a ray of light through glass and (2) to calculate the index of refraction from air to glass.

Apparatus. — Hard lead pencil with a fine point; ruler; protractor; compass; piece of plate glass with polished parallel edges; pins.

Experiment. — (1) About the middle of a sheet of paper draw a thin line, *LL'* (Fig. 55). Lay the glass plate on its side with one edge accurately on this line. Mark the outline of the glass. On one side of the glass plate set two pins *I* and *II* in a line, making an angle of about 45° with the edge of the glass plate. On the other side of the plate set two pins *III* and *IV* in line with the image of the pins *I* and *II*, as seen through the glass.

Remove the plate and draw a line through *I–II* meeting the refracting surface (the glass plate) at *A*. At what point did the ray of light through *I–II* enter the glass? In similar manner find the point at which the ray emerged from the glass. What was its path through the glass? Draw *AB*.

At *A* draw a normal to the refracting surface. Was the ray on entering the glass bent toward the normal or away from it? In similar manner draw a normal at *B* and answer the same question. What relation has the direction of bending to the speed of light in air and in glass? What is the relation in direction between the incident ray (*I–A*) and the emergent ray, *B–IV*? Describe precisely the effect which a retarding medium such as glass has upon light. Does the ray on entering a retarding medium bend toward the normal or away from it?

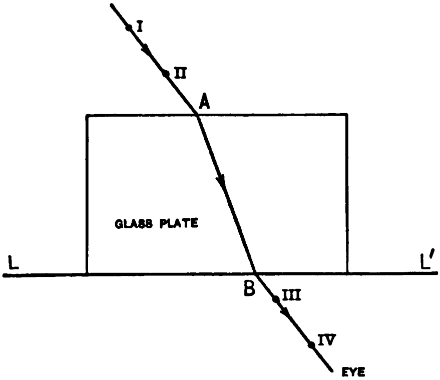


Fig. 55. — Path of the Refracted Ray

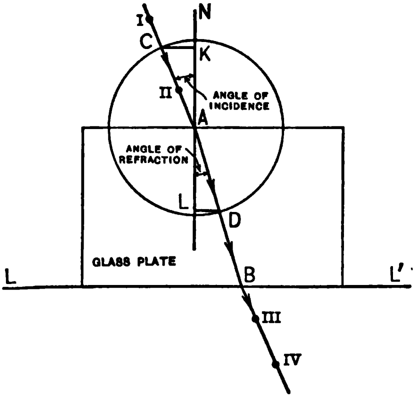


Fig. 56. — Index of Refraction

Experiment. — (2) With *A* as a center (Fig. 56) describe a circumference (preferably with a radius less than *AB*). Mark the intersection of *I–A* with circumference *C*, and the intersection of *A–B* with the circumference *D*. From *C* and *D* drop perpendiculars upon the normal at *A*. Measure the lengths of these perpendiculars. Their ratio is called the *index of refraction* from air to glass. In similar manner make a second calculation for the point *B*.

Repeat the experiment with a different angle of incidence.

Application. — Why does the water in a pail or pond appear more shallow than it really is?

TOTAL REFLECTION (Review Experiment)

Problem. — To observe the angle at which light passing from one medium to another is totally reflected.

Apparatus. — A triangular glass prism; pins; ruler; protractor; hard pencil.

Experiment. — Cut a piece of paper about the same size as one of the three rectangular faces of the prism. Draw a thin line about the middle of the paper and fasten the paper to the prism by paste or a rubber band so that the line is toward the glass.

Set the prism on one end and draw its outline, *ABC*, on the paper (Fig. 57). Indicate the position of the foot of this line by *P*. Move the eye back and forth in such a position that the line whose foot is *P* is seen through the glass. On moving far to one side the line disappears in a colored blur. Set two pins *I–II* along the line in which the image of *P* disappears.

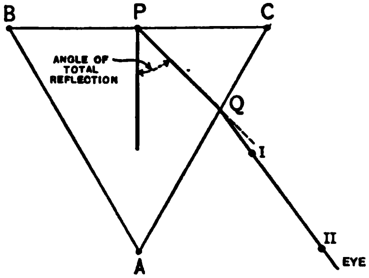


Fig. 57.—Path of Totally Reflected Ray

Remove the prism. Draw a line through *I* and *II* and extend it to the prism at *Q*. What path did the ray of light follow through the prism? Measure the angle of incidence of *QI* at *P*. Is this the critical angle for glass? Explain the meaning of critical angle.

Repeat this experiment two or three times. What is the average critical angle for this sample of glass?

Application. — 1. Why is all the light totally reflected that enters at right angles one of the equal faces of a 45° right-angled prism? (The critical angle for glass is less than 45°.)

2. How is prism glass used to throw light into cellars and poorly lighted rooms?

DEVIATION

Problem. — To observe the path of a ray of light through a prism.

Apparatus. — Triangular glass prism with one flat end; pins; hard pencil; ruler.

Experiment. — Hold the prism with its lateral edges horizontal and notice how one has to look in order to see an object through it. Does it change the apparent direction of the object ?

Set the prism on end near the middle of a sheet of paper and carefully draw its outline with a hard lead pencil. Set two pins as *I* and *II* (Fig. 58). View their images as seen through the prism (avoid the image of total reflection; it alone will be a colorless image), and set two other pins *III* and *IV* in line with their images.

Remove the prism. Produce the line *I–II* until it meets the prism at *P*. Similarly find the point where the line *III–IV* meets the prism. What is the path of the ray of light through the prism ? Is it parallel to the third face of the prism ? Does it have to be parallel with it ? Measure the angle *QRS*. It is the *angle of deviation*. How should it be defined ?

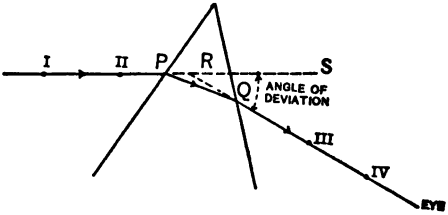


Fig. 58. — Path of Deviated Ray

Make at least three other trials with different angles of incidence. Is the angle of deviation always the same ?

Application. — Why should window panes have their two sides parallel ? Why does common window glass give a distorted image ? Why does plate glass give an undistorted image ?

DISPERSION

Problem. — To observe the effect which a prism has upon light passing through it; in particular to observe whether different colors pass through a prism along the same path, *i.e.* whether glass has the same index of refraction for all colors.

Apparatus. — A triangular prism; strips of colored papers (Bradley's or Prang's kindergarten colors); black paper; hard pencil; colored pencils.

Experiment. — Select the colors which are marked — violet, indigo, blue, green, yellow, orange, red, and white. Cut strips of each about 2 cm. long and 2 mm. wide. Draw a line along the middle of the sheet of black paper and paste the strips end to end along it in the order named (Fig. 59).

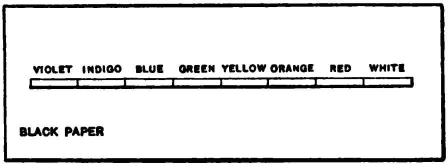


FIG. 59. — Color Board

Lay the paper in any strong light. Hold the prism near the eye in a horizontal position and rotate it until the deviated (not reflected) image of the strips of paper is clearly seen (Fig. 60). Into how many and what colors is the white resolved? Make a colored sketch. Repeat for the other colors.

Viewing the image through the prism, place the pencil point at the *apparent* place on the black paper where the blue appears. Now see how this point lies with reference to the strip of white paper. Repeat the observations for the other colors. Which color is deviated most? Which least? Arrange the colors in the order of their deviations.

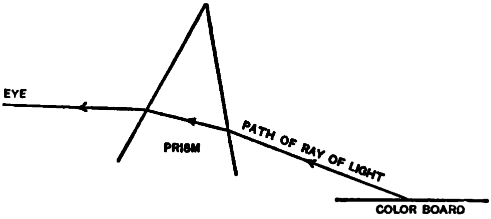


FIG. 60. — To see the dispersed image

Which color light travels fastest through glass? (Consult a table.) Which slowest? Which color has the shortest wave length? Which the longest? For which has glass the highest index of refraction? The lowest? Give a general statement connecting deviation with wave length, speed, and color. Why does a prism produce dispersion? What are the components of white light?

Application. — The images of objects as seen through a single prism are always edged with color. The index of refraction for crown glass is 1.52; that for flint glass 1.60. The dispersions of crown and flint glass are different. How could two prisms of crown and flint glass be combined to produce a colorless image? (Achromatic lens.)

FOCAL LENGTH OF A LENS

Problem. — To find the focal length of a convex lens.

Apparatus. — Convex lens and support; screen; needle mounted on a handle; meter stick and supports.

Experiment. — *Method 1.* Set up the lens and screen so that the image of some distant object is thrown upon the screen (Fig. 61). Measure the distance from the center of the lens to the screen. Make three settings and average. Is the image erect or inverted? To explain why, draw a diagram tracing the path of a ray of light through the lens.

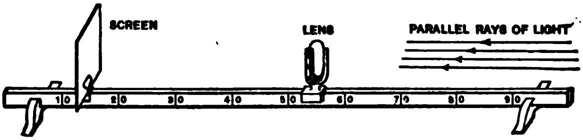


Fig. 61. — **Focal Length by Screen**

Method 2. Replace the screen by a mounted needle (Fig. 62). Bring the point of the needle into coincidence with the image of a distant object as seen through the lens. Move the eye from side to side and shift the needle point until needle and image move together (method of parallax). Why is the distance from lens to needle the focal length of the lens? Why is a distant object selected?

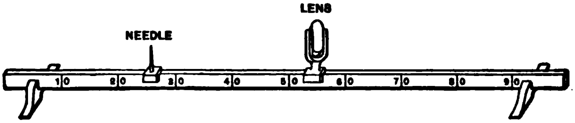


Fig. 62. — **Focal Length by Parallax**

Make two or three settings of the needle and average. Compare with the focal length as found by the first method.

Application. — In cheap cameras the lens is said to have a universal focus. What is meant?

In focusing cameras a scale is furnished showing where to set the lens for distances up to 100 ft. Why is the scale not continued for distances greater than 100 ft.?

CONJUGATE FOCI

Problem. — To find the relation between the conjugate focal lengths of a lens and its focal length.

Apparatus. — Convex lenses and supports; screen; candle or other source of light; wire gauze; meter stick and supports (Fig. 63).

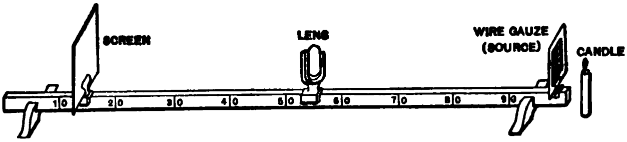


FIG. 63.—Conjugate Foci

Experiment. — Place the flame behind the wire gauze. Set the lens at a distance from the gauze several inches greater than its focal length. Move the screen until a sharp image of the gauze is received on the screen. Measure the distance from the lens to the screen and from the lens to the gauze. Call one distance u and the other v. Is it true that $\frac{1}{u}+\frac{1}{v}=\frac{1}{F}$, where F is the focal length of the lens? u and v are called *conjugate focal distances.* Repeat the experiment, setting the lens at different distances from the gauze.

What relation exists between the sizes of image and object and their distances from the lens?

Application. — How could two lenses be used to form a telescope? Try the experiment and explain why the images are inverted.

How could two lenses, one convex and one concave, be used to form an opera glass?

THE CONVEX MIRROR (Review Experiment)

Problem. — To study the image formed when light is reflected from a convex cylindrical mirror.

Apparatus. — A convex cylindrical mirror; ruler; pins.

Experiment. — Draw the outline of the reflecting surface. At about its middle draw a line *ON* normal to the reflecting surface (Fig. 64) and produce it behind the mirror. It is the *axis* of the mirror.

Set up two pins *I* and *II* along a line parallel with the axis and find the reflected ray. Repeat for the pins *III* and *IV*. The intersection of these reflected rays is the *principal focus*. Why? Is it behind the mirror or in front of it? Is the image formed *real* or *virtual?* Are the laws of plane reflection followed for each ray?

Set up a pin at some point on the axis, as *P*, and locate its image. If *u* and *v* are the distances of image and object from the mirror, is it true that $\frac{1}{u}+\frac{1}{v}=\frac{1}{F}$, where *F* is the principal focal distance? Why must a minus sign be given to the distance *v*? What is the relation between *u* and *v* and the sizes of image and object?

Are the images in a convex mirror ever real? Are they ever as large as the object?

Application. — What kind of a mirror is the so-called "fat man's" mirror?

The small mirror attached to an automobile to enable the chauffeur to watch the street behind him is frequently made convex. Why?

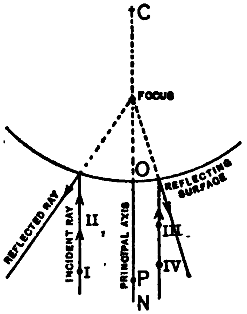


Fig. 64. — The Convex Mirror

THE CONCAVE MIRROR (Review Experiment)

Problem. — To study the image formed when light is reflected at a concave cylindrical surface.

Apparatus. — A concave cylindrical mirror; ruler; pins.

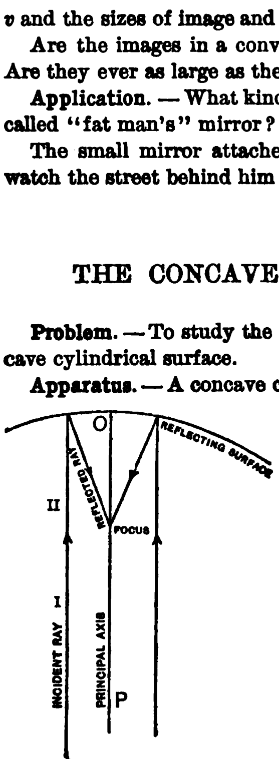


Fig. 65. — The Concave Mirror

Experiment. — Draw the outline of the reflecting surface at about the middle of the sheet of paper. At about the middle of the outline select a point *O* and draw a normal to the mirror, *ON* (Fig. 65). *ON* is called the *axis* of the mirror. About 5 mm. to the left draw a parallel to *ON* and along it set two pins *I* and *II*. Locate the reflected ray.

Repeat for another line 5 mm. to the right of *ON* and also for a third line somewhere between these two. Do these reflected rays meet at a point? It is called the *principal focus* of the mirror. Is the image formed at the focus *real* or *virtual?* Are the laws of plane reflection followed by each ray?

Set up a pin at some point on the axis, as *P*, and locate its image. If *u* and *v* are the distances of image and object from the mirror, is it true that

$\frac{1}{u}+\frac{1}{v}=\frac{1}{F}$, where F is the principal focal distance? The distances u and v are called *conjugate focal distances.*

Find a position of P where the incident and reflected ray follow the same path. Is this the center of curvature of the mirror?

What is the relation between u and v and the sizes of image and object?

What happens to the image if the object lies inside the focal distance? What is a virtual image?

Under what circumstances is the image in a concave mirror real? Under what circumstances is it virtual?

Application. — How is a concave mirror used in a reflecting telescope?

SPECTRUM ANALYSIS (Review Experiment)

Problem. — To observe the spectra of carbon, various metals, and the sun, and to explain the Fraunhofer lines.

Apparatus. — A 60° glass prism; sheet of tin or iron about 12 × 12 in. with a slot about ¼ in. wide and 6 in. long cut in the middle of one side (Fig. 66); Bunsen flame; pieces of red and blue glass; chemically pure solutions of sodium chloride, lithium chloride and thallium sulphate; a platinum wire mounted in a glass handle for each solution; a direct vision spectroscope; colored pencils.

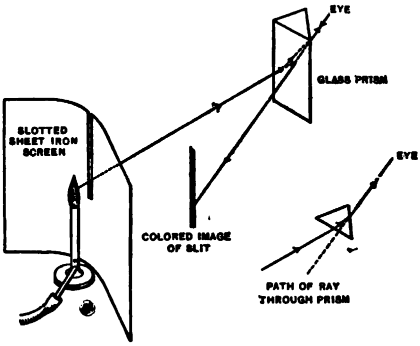


FIG. 66. — A Spectrum

Note. — Each platinum wire must be thoroughly cleaned before putting it into its solution. This is done by heating it very hot in the Bunsen flame and then plunging it, while still hot, into concentrated hydrochloric acid and again reheating. This operation is repeated until the flame remains colorless when the wire is heated in it. Almost all solutions are likely to show the sodium line at least faintly.

An iron wire may be used instead of platinum, but it must not be cleaned with hydrochloric acid.

Experiment. — Set the Bunsen burner with closed air holes (or a candle), behind the screen, and view the flame through the prism (Fig. 66). Describe the colored image thus seen. It is the spectrum of solid carbon. Draw a diagram in colors, assigning to each color about the space it appears to occupy in the image. Is it *continuous or discontinuous?* This spectrum is characteristic of all hot solids. It differs greatly from the spectra of their vapors.

Open the air holes of the burner so as to get a colorless flame. View it through the prism as before. Bring into the flame a wire dipped into a solution of sodium chloride (or any salt of sodium). Do you get one or more bright images of the slit? In what color or colors are they? Is this spectrum continuous or discontinuous? Describe the spectrum of sodium. It is a *bright line* spectrum. The characteristic line is called the *D* line. Its wave length is about 0.00005896 cm. Draw a diagram under that of the carbon spectrum and make a colored line under the color where the *D* line appeared.

In similar manner introduce some solution of a salt of thallium into the flame. Describe the spectrum and draw a diagram as before. The wave length for this line of thallium is 0.00005349 cm.

Repeat with a solution of a salt of lithium. Describe spectrum and draw diagram as for sodium. The wave length of the chief lithium line is 0.00006708 cm.

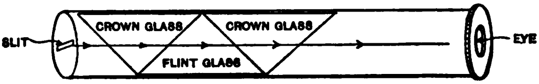


FIG. 67. — Direct Vision Spectroscope

Compare your diagrams with a chart of spectra. Have you seen all the lines actually present in the spectra of the metals? Why not?

View the sodium spectrum through blue glass; through red glass. The colored glass absorbs some of the colors, forming an *absorption* spectrum. View the yellow flame through colored glass. What colors pass through blue glass? red glass?

Experiments with the Spectroscope. — Point the direct vision spectroscope (Fig. 67) toward the bright sky, narrow the slit and focus it sharply. The dark lines *parallel* with the colors are Fraunhofer lines, due to the fact that the sun's spectrum is an absorption spectrum. The dark lines coincide with the position of the bright lines characteristic of the spectra of sodium, iron, nickel, and other elements. The spectra of these elements have been absorbed by the cooler layers of hot gases in the sun's atmosphere.

Application. — How might the presence of sodium, thallium, etc., in a mixture be detected by the spectroscope? How do we know the composition of the sun and stars?

THE INTERNATIONAL METRIC SYSTEM OF WEIGHTS AND MEASURES*

FACTS ABOUT THE METRIC SYSTEM

1791. — Reported to the French National Assembly by the Academy of Sciences.

1799. — Accepted by Holland, Denmark, Switzerland, Spain, and several minor states.

1866. — Made, by Act of Congress, "lawful throughout the United States."

1875. — Permanent organization by seventeen nations of an International Bureau of Weights and Measures, with headquarters at Sèvres, near Paris.

1893. — International prototype meter and kilogram made fundamental standards.

ADVANTAGES OF THE METRIC SYSTEM

(i) The decimal relation between the units, greatly facilitating computation.

(ii) The extremely simple relation of the units of length, area, volume, and weight to one another.

(iii) The uniform and self-defining names of units.

SYNOPSIS OF THE SYSTEM

The fundamental unit of the metric system is the **meter** — the unit of length. From this the units of capacity (liter) and of mass (**gram**) are derived. All other units are the decimal subdivisions or multiples of these three simply related units. For all practical purposes *one cubic decimeter equals one liter*, and *one liter of water weighs one kilogram.* The metric tables are formed by combining the words *meter*, *gram*, and *liter* with the six numerical prefixes, as in the following tables:

PREFIXES	MEANING	UNITS
milli-	= one thousandth $= \frac{1}{1000} = 0.001$	**meter** for length
centi-	= one hundredth $= \frac{1}{100} = 0.01$	
deci-	= one tenth $= \frac{1}{10} = 0.1$	
(unit)	= one	**gram** for weight or mass
deka-	= ten $= \frac{10}{1} = 10.$	
hecto-	= one hundred $= \frac{100}{1} = 100.$	
kilo-	= one thousand $= \frac{1000}{1} = 1000.$	**liter** for capacity

---

* The major part of this description of the Metric System is taken from a pamphlet of this title published by the Bureau of Standards and obtainable from the Department of Commerce and Labor, Washington, D.C. The Tables and Equivalents are from the Smithsonian Physical Tables (1908).

Linear Metric Measure

1 milli-meter (mm.) = 0.001 meter 10 mm. = 1 cm.
1 centi-meter (cm.) = 0.01 meter 10 cm. = 1 dm.
1 deci-meter (dm.) = 0.1 meter 10 dm. = 1 m.
***1 meter (m.) = 1 meter**
1 deka-meter (Dm.) = 10 meters 10 m. = 1 Dm.
1 hecto-meter (hm.) = 100 meters 10 Dm. = 1 hm.
1 kilo-meter (km.) = 1000 meters 10 hm. = 1 km.

Metric Measure of Area

The table of areas is formed by squaring the measures of length, as in our common British system.

100 sq. mm. = 1 sq. cm. 1 sq. in. = about 6½ sq. cm.
100 sq. cm. = 1 sq. dm.
100 sq. dm. = 1 sq. m.
100 sq. m. = 1 sq. Dm. = 1 are.
100 sq. Dm. = 1 sq. hm. = 1 hectare = about 2½ acres.
100 sq. hm. = 1 sq. km. 1 acre = about 0.4 hectare.

Metric Measure of Volume

The cubic measures are the cubes of the linear units.

1000 cu. mm. = 1 cc.
1000 cc. = 1 cu. dm.
1000 cu. dm. = 1 cu. m.

The *cubic meter* is the unit of volume. *A cubic meter of water weighs a "metric ton"* and is equal in weight to 1 *kiloliter* of water. The thousandth part of the cubic meter, namely, 1 cubic decimeter, is called the liter. For very small volumes the cubic centimeter is used. *One thousand cubic centimeters make one liter.*

1 cu. dm. = 1000 cc. = 1 liter (l.)
1 liter = 1.05668 liquid quarts, or 0.9081 dry quarts.

Metric Measure of Weight (or Mass)

One cubic centimeter of water weighs with sufficient accuracy for all practical purposes a *gram*, which is the unit of mass. A liter of water weighs 1 kilogram, *i.e.* 1000 grams. A thousand liters of water weigh a metric ton.

---

* In the United States one meter equals 39.37 inches exactly.

1 milli-gram (mgm.) = 0.001 gram (gm.)
1 centi-gram (cgm.) = 0.01 gram
1 deci-gram (dgm.) = 0.1 gram
1 gram (gm.) = 1 gram
1 deka-gram (Dgm.) = 10 gram
1 hecto-gram (hgm.) = 100 gram
1 kilo-gram (kgm.) = 1000 gram

10 mgm. = 1 cgm.
10 cgm. = 1 dgm.
10 dgm. = 1 gm.

10 gm. = 1 Dgm.
10 Dgm. = 1 hgm.
10 hgm. = 1 kgm.

1 kilogram = 2.204622 avoirdupois pounds.

For foreign postage 30 grams is the equivalent of the avoirdupois ounce.

Customary, or British Measures

Length

12 inches (in.) = 1 foot (ft.)
3 ft. = 1 yard (yd.)
5½ yd. = 1 rod (rd.)
40 rd. = 1 furlong
8 furlongs = 1 mile (mi.)

Area

144 sq. in. = 1 sq. ft.
9 sq. ft. = 1 sq. yd.
30¼ sq. yd. = 1 sq. rd.
160 sq. rd. = 1 acre (A.)
640 A. = 1 sq. mi.

Volume

1728 cu. in. = 1 cu. ft.
27 cu. ft. = 1 cu. yd.

Dry Measure

4 gills (gi.) = 1 pint (pt.)
2 pt. = 1 quart (qt.)
8 qt. = 1 peck (pk.)
4 pk. = 1 bushel (bu.)

Liquid Measure

16 fluid ounces (fl. oz.) = 1 pt.
2 pt. = 1 qt.
4 qt. = 1 gallon (gal.) = 231 cu. in.
31½ gal. = 1 barrel (bbl.)

Weight (or Mass)

Avoirdupois

16 drachms = 1 ounce (oz.)
16 oz. = 1 pound (lb.)
2000 lb. = 1 ton (T.)

Troy

24 grains (gr.) = 1 pennyweight (pwt.)
20 pwt. = 1 ounce (oz.)
12 oz. = 1 pound (℔.)

Apothecaries

20 grains (gr.) = 1 scruple
3 scruples = 1 dram
8 drams = 1 ounce
12 ounces = 1 pound

5760 grains = 1 ℔. apothecaries or troy.
7000 grains = 1 lb. avoirdupois.

CUSTOMARY AND METRIC EQUIVALENTS

1 inch	= 2.54001 cm.	1 cm.	= 0.3937 in.
1 foot	= 30.4801 cm.	1 m.	= 39.37 in.
1 yard	= 91.4402 cm.	1 m.	= 1.0936 yd.
1 mile	= 1.60935 km.	1 km.	= 0.62137 mi.
1 sq. in.	= 6.452 sq. cm.	1 sq. cm.	= 0.1550 sq. in.
1 sq. yd.	= 0.836 sq. m.	1 sq. m.	= 1.196 sq. yd.
1 cu. in.	= 16.387 cc.	1 cc.	= 0.0610 cu. in.
1 cu. ft.	= 28.32 cu. dm.	1 cu. dm.	= 61.023 cu. in.
1 cu. yd.	= 0.765 cu. m.	1 cu. m.	= 1.308 cu. yd.
1 qt. dry	= 1.13649 l.	1 l.	= 0.9081 qt. dry
1 qt. liquid	= 0.9463 l.	1 l.	= 1.0567 qt. liquid
1 ounce troy	= 31.10348 gm.	1 gm.	= 0.03215 ounce troy
1 ounce avoirdupois	= 28.34953 gm.	1 gm.	= 0.03527 ounce avoirdupois
1 lb. avoirdupois	= 453.59243 gm.	1 kgm.	= 2.2046 lb. avoirdupois

USEFUL NUMBERS

1. $g = \text{about } 980 \dfrac{\text{cm.}}{\text{sec.}^2} = \text{about } 32 \dfrac{\text{ft.}}{\text{sec.}^2}$. $\pi^2 = 9.8696$.

2. 1 HP = 550 foot-pounds of work per second = 33,000 ft.-lb per minute = 746 watts.

3. 1 calorie = 42,000,000 ergs = 0.428 kilogram-meter.

4. 778 foot-pounds of work can raise 1 lb. of water 1° Fahrenheit.

5. 1 ampere deposits silver at the rate of 0.001118 gm. per second.

6. The velocity of sound in air at 0° C. is 332 meters per second or about 1090 feet per second, and changes 0.6 meter per second or about 2 feet per second for each degree centigrade.

7. The velocity of light is 300 million meters per second or 186,000 miles per second.

8. The heat of fusion of ice at 0° C. is 80 calories per gram.

9. The heat of vaporization of water at 100° C. is 536 calories per gram.

10. The specific heat of ice is about 0.505.

11. Circumference of a circle equals diameter multiplied by 3.14159 (about $\frac{22}{7}$), or $cir. = 2\pi r$.

12. Area of a circle equals radius squared multiplied by 3.14159, or $area = \pi r^2$.

13. Volume of a sphere equals one sixth the cube of the diameter multiplied by 3.14159, or $vol. = \frac{1}{6}\pi d^3$.

14. To find the hypotenuse of a right-angled triangle, extract the square root of the sum of the squares of the base and altitude (Pythagorean Theorem).

15. One liter of air, N.T.P., weighs 1.293 gm. One cu. ft. of air at 20° C. weighs about .08 lb.

16. $\sqrt{2} = 1.414$, $\sqrt{3} = 1.732$, $\sqrt{5} = 2.236$, $\sqrt{10} = 3.162$.

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